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THE AFFERENT NERVOUS SYSTEM FROM A NEW ASPECT.[1]

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IT has long been recognised, by all who have interested themselves in the problems of sensation, that no view yet advanced of the structure and functions of the afferent nervous system is sufficient to explain obvious facts. The teaching of the anatomist throws little light on the difficulties with which the surgeon is confronted. On the other hand, it is difficult to reconcile the various views concerning the nature of common sensibility with the facts of clinical experience.

Such want of correspondence between observed facts

[1] The substance of this paper was delivered on May 23, 1905, before the Royal Medical and Chirurgical Society as the Marshall Hall address.

and the prevailing general ideas showed that the distribution and function of the peripheral nerves required reconsideration. In the present paper we shall put forward a new view of the mechanism of sensation, based upon several different lines of research. If we may seem unduly to neglect the work of others, let it be remembered that this paper is introductory to a series of communications, each of which will deal with one aspect of the subject more exhaustively than is possible in a preliminary statement of a new hypothesis.

When the median nerve is divided, sensation is entirely lost over a considerable part of both the index and middle fingers. Over the palm, within the area said by the anatomists to be supplied by this nerve, sensation is usually diminished and not completely abolished. In a similar manner, division of the ulnar nerve produces complete insensibility of the little finger, and of a variable portion of the ulnar aspect of the palm; but partial loss of sensation is found over a larger area of the palm and the ulnar half of the ring finger. Such is the usual statement of surgeons and anatomists. When they are asked, why sensation is only partially lost over the palm, the usual answer is, "Because there the nerves overlap." But if each nerve occupies the territory of the other to an extent sufficient to prevent absolute loss of sensation over so large a portion of the palm, it is obvious that destruction of the ulnar nerve must cause some diminution of sensibility over the median half. This loss should vary exactly in proportion to the amount of sensation that remains, after the median has been destroyed. But the most careful examination of the hand fails to show the slightest diminution in sensation over the median half of the palm in consequence of division of the ulnar nerve. What has always been called the diminished sensibility produced by the division of a nerve is really a condition in which some kinds of sensibility are lost and others retained. Within such a region of altered sensibility all sensation to light touch is abolished. If, in a patient who has divided his ulnar nerve, the ulnar half of the palm of the hand is stimulated with

cotton-wool, no sensation will be produced, while the lightest touch will be appreciated directly the line corresponding to the axis of the index finger is transgressed. If the area is large enough to apply a pair of compasses, it will be found that the patient is totally unable to appreciate two points two centimetres apart. Not only is sensation abolished to these tests, but careful examination shows that temperatures between 22° C. and 40° C. are not appreciated over this area. Thus, parts which have universally been considered to be areas of diminished sensibility turn out to be totally insensitive to certain higher forms of stimulation.

When the hand has settled down after the shock of the injury that has divided one or more of the nerves to the palm, it will be found that, although the area we have spoken of is totally insensitive to certain higher forms of stimulation, a stimulus producing pain, *e.g.*, a prick of a pin, causes a more unpleasant effect than over normal parts.

If the nerve has been united, sensation begins to return after a variable interval. The first sign of recovery is a gradual diminution in the extent of the area insensitive to pain and to all forms of heat and cold.

Finally, no part of the affected hand remains completely insensitive to all cutaneous stimuli. It is to the condition of a hand at this stage of recovery that we wish to draw particular attention. It might be supposed that, with the gradual disappearance of analgesia, an improvement would follow in the higher forms of sensibility. This is not so The boundary at which light touch is lost is as definite as in the days following the injury, although sensibility to pain, to heat and to cold, has vastly improved. In this condition the hand may remain for many months, before light touch begins to be appreciated over parts that lie within the borders of altered sensibility.

Closer examination of parts in this condition shows that, although the hand has become sensitive to pain and to temperature, this sensibility is strangely altered. A prick is appreciated, but produces a sensation that radiates widely over the affected area. It causes unnatural discomfort,

and the patient has an uncontrollable desire to withdraw his hand. Moreover, although ice and water at a temperature of 50° C. are appreciated as cold and hot, intermediate degrees produce no sensation of temperature, and water at 25° C. or 26° C. may be indistinguishable from water at 40° C.

We assured ourselves of the truth of these conclusions during more than two years spent in watching patients who had come to the London Hospital on account of injuries to one or more peripheral nerves. But it became obvious, that in order that we might examine more exhaustively the sensory condition of parts that had been robbed of their nerve supply, it was necessary that the patient should be a trained observer, and the injury determined beforehand.

On April 25, 1903, the radial (ramus cutaneus n. radialis) and external cutaneous nerves were divided in the neighbourhood of my elbow, and after small portions had been excised, the ends were united with silk sutures. Before this operation, the sensory condition of the arm and back of the hand had been minutely examined, and the distance at which two points of the compass could be discriminated had been everywhere measured.

This operation produced loss of all forms of cutaneous sensibility over an extensive area on the radial half of the forearm and back of the hand. Stimulation with cotton-wool, the prick of a pin, the application of all forms of heat and cold, were unappreciated, and the two points of the compasses could not be discriminated, even when separated to the furthest extent possible. But if this part was touched with the point of a pencil, the head of a pin or even with the ball of the finger, the stimulus was at once appreciated, and the point of application localised with remarkable accuracy. (Plate I., fig. 1.)

We are thus face to face with the conclusion, that complete destruction of all the sensory nerves to the skin leaves the part sensitive to most of those stimuli commonly used by the physician and surgeon as a test of sensibility to touch. With the Graham-Brown æsthesiometer, an instrument which measures the appreciation of irregu-

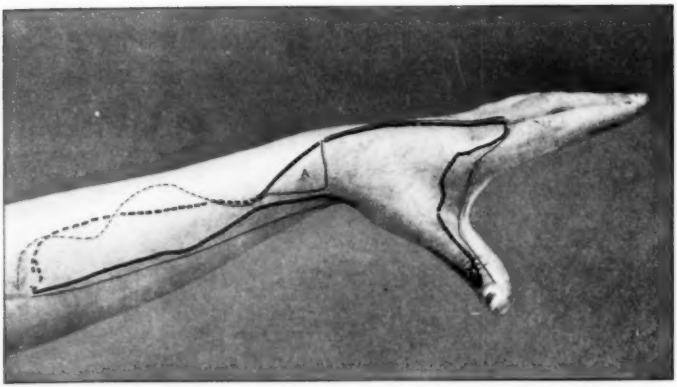

FIG. 1.

To show the loss of cutaneous sensibility produced by dividing the radial (ramus superficialis n. radialis) and external cutaneous nerves in the neighbourhood of the elbow. The thick line bounds the area insensitive to prick. The thinner line encloses the parts insensitive to cotton wool. Both the thick and the thin line are dotted wherever the borders of the area of loss of sensibility were not sharply defined.

The triangle marked **A** was insensitive to prick but sensitive to stimulation with cotton wool.

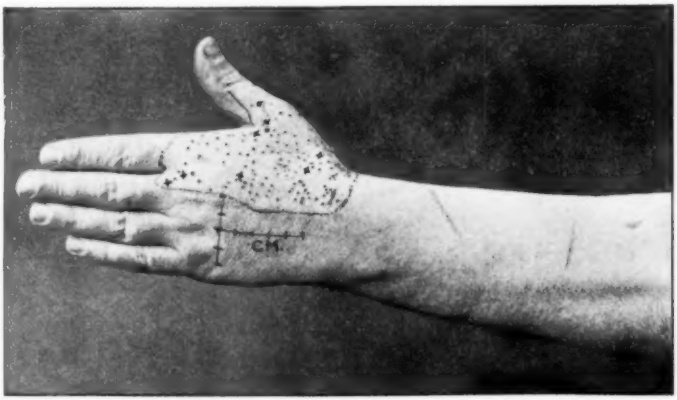

FIG. 2.

The area enclosed within the black line had become sensitive to prick, to water at 50° C. and to ice, but was insensitive to cotton wool, to water at 25° C. and to water at 38° C. The dots within this area are cold spots, the crosses mark the position of the hot spots. The two lines outside the affected area are divided into centimeters.

larities in an otherwise smooth surface, the hand that had been robbed of all its cutaneous sensibility was found to be actually more sensitive than a similar part on the normal side.

Since all the nerves had been divided which supplied the skin, the maintenance of this sensibility must have been due to afferent fibres running with motor nerves. Sherrington (1) has demonstrated the existence of such sensory fibres and traced them to the muscles, tendons and joints. By the operation on my arm, we had gained the unique opportunity of exposing a part, endowed only with deep sensibility, to a series of careful tests.

The peculiar aptitude, possessed by a part innervated solely by the afferent fibres of a muscular nerve, is the appreciation of all stimuli which produce deformation of structure. Pressure or any jarring of the skin was quickly appreciated in my case, and, on the whole, was localised with remarkable accuracy. But, when the hairs were pulled, the elevation of the skin produced no effect upon consciousness. Pressure, which had previously caused a sensation, was no longer appreciated when applied to the skin lifted from the subcutaneous structures to form a ridge. This showed that the sensibility to pressure was not due to nerves still remaining in the skin after the operation. Although pressure was localised with considerable accuracy, all sense of form and size was lost over the parts affected. The prick of a pin and the interrupted current were entirely unappreciated; but excess of pressure produced aching pain. When the pressure was produced by means of Cattell's algometer, it was found that pain was elicited with a smaller pressure of the instrument than on the sound side. The affected parts could be burnt without producing pain, and no sensation of cold was produced, even when the hand was frozen firmly by means of ethyl chloride.

This condition remained unaltered until seven weeks after the operation, when sensation of prick began to return on the arm. Six weeks later, there was no part of the forearm where prick could not be appreciated, and within 200 days from the time when the nerves were

divided, even the back of the hand had become sensitive to this form of stimulation. Yet, for more than a year, both forearm and hand remained completely insensitive to light touch, and even now, more than two years after the operation, the hand has not completely regained its sensibility, when tested with cotton-wool and with the compasses.

Thus, we had ample opportunity of examining with care the sensory condition of a part sensitive to prick, but insensitive to light touch. We found that, when the forearm or hand was pricked, the pain produced was not localised, but radiated widely, and was not infrequently referred to some part at a distance from the point stimulated. Ice and water at 50° C. were appreciated, but minor degrees of temperature produced no effect upon consciousness. This peculiarity in the behaviour of the hand and forearm we found to be due to what are known as "cold" and "hot spots." (Plate I., fig. 2.)

Blix (2) first described the presence of "cold spots" in the skin, and his work was amplified by Goldscheider (3). To some observers, such as von Frey (4), all forms of sensation possessed by the skin are due to the existence of small areas of specific sensibility. So extreme a view has been accepted by few; some even doubt the very existence of temperature spots. By suitable methods spots can be demonstrated in the normal skin where cold alone can be appreciated; analogous spots, more sparsely scattered, can also be shown to be devoted entirely to sensations of heat. In the same way it would seem that there are spots peculiarly sensitive to the prick of a sharp needle; but the disturbance produced by their stimulation is so great, that they cannot be demonstrated with the same certainty as the spots devoted to sensations of temperature. Now *pari passu* with the return of sensibility to prick and to the extremes of heat and cold, these spots reappeared upon my arm and hand. But whereas, in the normal skin, the hot and cold spots are nothing more than minute areas peculiarly sensitive either to heat or to cold, set in a territory over which temperature stimuli can also be appreciated, the spots which made their reappearance on my arm during the first stage of recovery

were set in an area insensitive to temperature stimulation. Thus, they were not only discoverable with unusual ease, but, since the only form of temperature sensation possessed by the recovering part was due to their presence, it was particularly easy to investigate their sensory peculiarities. The cold spots could be stimulated by any temperature below about 24° C.; but, whenever a spot reacted, what might be called an explosion of cold was produced, not localised at the point touched, but radiating widely, sometimes even to a very considerable distance. A small group of spots on the wrist always produced a sensation of cold in the forearm just below the fold of the elbow, and two spots in the forearm, when stimulated, evoked a sensation of cold in the thumb. The hot spots, more sparsely scattered, behaved in a similar manner. The lower limit of temperature to which they reacted varied from 38° C. to 45° C. One extremely sensitive spot even reacted to 37° C. But, whether these spots reacted slowly or briskly, the sensation was always one of widespread heat, and, until the painful limit of heat was reached, it mattered little at what temperature the stimulus was applied, provided it lay within the limits capable of stimulating these spots. The following experiment, which demonstrates this peculiarity, was many times repeated with the same results. A cold spot of unusual activity was stimulated by means of a copper cylinder of one millimetre diameter, cooled to the temperature of melting ice. This produced a sensation of cold. Water at 20° C. was placed in a test tube with a flat bottom of one centimetre diameter, and this was applied to the skin in such a way that it stimulated a constellation of spots, among which lay the spot originally stimulated. The sensation of cold produced by this stimulus was more intense than that produced by stimulating a single spot with a temperature considerably lower. Thus we come to the remarkable conclusion that the hot and cold spots are incapable of producing, in consciousness, graduated sensations of heat or of cold. Water at 20° C. can be made to appear colder than ice, provided the stimulus is so arranged that the former is applied over a considerably larger area

than the latter. Such spots resemble in their action the cold alarms of our greenhouses. When the temperature falls below a certain amount, a bell is rung, but no indication is given of the extent to which the temperature has fallen.

Although we had peculiar difficulty in demonstrating the presence of similar spots for pain, the general behaviour of a part in this stage of recovering sensibility, closely resembles that of the hot and cold spots. Radiation takes place widely; a more intense stimulus is necessary to evoke pain, but when evoked, the pain is greater than over the normal skin. We also found that in this stage of recovery many of the hairs had gained a peculiar sensibility. When a hair on the normal skin is gently lifted, a sensation of touch is caused which is extremely well localised. But in the stage of recovery we are now discussing, the movement of the hairs produced a curious widespread formication, with the same reference to distant parts as in the case of temperature and pain.

However widespread the radiation may be to prick, to heat, to cold, or on touching the hairs, it is not fortuitous in its distribution. We found, by repeated experiment, that certain areas on the hand always caused radiation into some other part irrespective of the form of stimulation.

All these facts would seem to show that we are here face to face with an undiscovered form of sensibility, capable of producing qualitative changes in consciousness, but incapable of causing a quantitative change apart from the extent of area stimulated. The position of the point stimulated cannot be recognised and each stimulus causes a widespread, radiating sensation, not infrequently referred to parts at a distance. To this form of sensibility we propose to give the name "*protopathic.*"

The return of protopathic sensibility brings a cessation of all those destructive changes in nutrition that occur in parts where the skin is insensitive. Ulcers form, as the consequence of burns or cuts, and do not heal so readily as on the normal skin. But such trophic changes are confined to parts insensitive to protopathic stimuli. With the return of protopathic sensibility, ulcers cease to form, and

sores heal as readily as on the normal skin, although the parts remain insensitive to all the higher forms of stimulation, such as light touch. Thus a part supplied by protopathic sensibility alone grows, and is repaired, as easily as the normal skin.

After the affected part has remained for a variable period in this condition, it begins to become sensitive to light touch, and degrees of temperature, which produce the sensations called "warm" and "cool" on the normal skin, are again distinguished correctly from one another. With the gradual return of sensation, it again becomes possible to discriminate two points touching the skin at distances more nearly normal, and the widespread radiation, so characteristic of the first stage of recovery, ceases, and is replaced by an increasing accuracy of localisation. To this form of sensibility we propose to give the name "*epicritic*," since it is peculiarly associated with the localisation and discrimination of cutaneous stimuli.

So far we have demonstrated the existence in the skin of two forms of sensibility, but have brought forward no evidence to show that they depend upon anything more than modifications of the same system of nerve fibres and end organs.

I can now deal with a curious phenomenon that occurred in the case of my arm. Over the radial half of the dorsum of the wrist, a triangular area of skin became entirely insensitive to prick in consequence of the operation. But this same area remained sensitive to touches with cotton-wool, and also, in a limited degree, to warmth. The area was small, and its epicritic sensibility was of a low order, but in spite of these disadvantages, it became obvious, after repeated testing, that the area was capable of appreciating temperatures between 36° C. and 45° C. It was, however, entirely insensitive to temperatures of 50° C. and above. To ice and to all forms of cold, this part was equally insensitive. It would therefore seem that, by a fortunate chance in nerve distribution, we had divided those fibres which subserved protopathic sensibility, leaving untouched, at any rate, some of those which conducted the

impulses of epicritic sensibility. Such an observation can only be explained by assuming that the two forms of sensibility depend upon two separate systems in the peripheral nerves. Experiments with so delicate a sensory change can only be carried out satisfactorily by frequent repetition, by selection of occasions when the patient is, from the sensory point of view, in excellent condition, and under the rigid check of a large number of controls. These conditions are rarely, if ever, satisfied during the examination of patients in whom the loss of sensation has been produced by accident. We have, however, seen this dissociation of sensibility in a patient where, during the removal of a small tumour from the nerves at the base of the brain, Sir Victor Horsley produced profound loss of sensation to prick over the one-half of the face, unaccompanied by an equivalent loss of sensibility to light touch. Here there could be no doubt that the patient could appreciate warmth, but not heat, and he many times stated that a temperature of 55° C. was neither hot nor cold, but that 43° C. was undoubtedly warm.

The mode of recovery of sensation after injury to a peripheral nerve also supports the view, that these two forms of sensibility depend upon separate structures. If the nerve has been completely divided, protopathic sensibility returns first, followed at a considerably later period by return of epicritic sensation. Provided the nerve has been completely divided, we have never seen the faintest sign of returning epicritic sensibility, unless sensation to prick had already shown material improvement. But, if the nerve is only bruised or injured, so that its continuity is functionally, but not structurally, destroyed, the two forms of sensibility may return *pari passu*.

Evidently, the two systems regenerate with unequal facility. The protopathic system regenerates more rapidly and with greater ease. It can triumph over want of apposition and the many disadvantages that are liable to follow traumatic division of a nerve.

Moreover, the length of the nerve to be regenerated makes relatively little difference to the time at which protopathic

sensibility returns. Although the nerves in my arm were divided at a point at least 20 cm. above the wrist, recovery began in seven weeks and was completed, even over the hand, in twenty-nine weeks. This compares favourably with most of our instances of primary suture, in which the nerve was divided at the wrist. But this is in no way true of the epicritic system. Provided the wound is healthy, and the operation of the primary suture has been successfully performed, the length of time required for epicritic regeneration depends upon the distance of the wound from the periphery. And this is why, in my case, the period between the close of the first stage and the beginning of the second stage of recovery was unusually prolonged.

Every peripheral nerve contains in varying proportion the fibres subserving these two forms of sensibility. Let us consider for a moment their distribution in the nerves, the trunks and the roots which supply the upper limb.

To simplify what must of necessity be a somewhat complex statement, I will deal first with the supply of epicritic sensibility only. On the palm of the hand, the area supplied by the ulnar and median nerves overlaps to an extent less than one-half the breadth of the finger. Consequently, the borders of the insensitive area produced by division of one or other of these nerves is well defined. The back of the hand can be roughly divided into two halves, by a line running from the knuckle of the middle finger to the middle of the back of the wrist. On the ulnar side of this line, the hand is supplied by the ulnar and internal cutaneous, on the radial side by a combination of external cutaneous, the radial and the long cutaneous branch of the musculo-spiral. If we now include the forearm, it will be found that a line drawn up the flexor surface continuous with the axis of the ring finger, and up the extensor surface, continuous with the line just mentioned on the back of the hand, divides the whole of the forearm and hand into a pre-axial and a post-axial portion. Of these the post-axial portion is supplied by the ulnar and internal cutaneous, the pre-axial portion by the median, the radial, the external cutaneous, and the long branch of the musculo-spiral.

Another border, which has the same character as these two axial lines, is the boundary separating the distribution of the median from that of the group of nerves supplying the radial half of the dorsal surface of the hand.

Whenever division of any nerve branch causes loss of sensation to light touch along one of these lines, that border will be well defined. Division of one branch only will produce no definite area of anæsthesia, unless that area is bounded by one or more of these lines.

Thus, provided the peripheral nerves are gathered into certain groups, it may be said that from the point of view of light touch, and other forms of epicritic sensation, very little overlapping occurs. These groups are as follows: (1) The ulnar and internal cutaneous; (2) the median; (3) the remainder of the pre-axial group.

From this arrangement, the distribution of protopathic sensibility differs fundamentally. Enormous overlapping occurs, as we have already seen from a consideration of the analgesia caused by division of the median or of the ulnar nerves. Evidently, the peripheral nerves, looked at broadly, form the units of epicritic supply. On the contrary, from the protopathic point of view, no one nerve forms anything more than a tributary supply of an area innervated by a plexus of nerves, and, whenever a single peripheral nerve is destroyed in the upper limb, the loss of light touch always exceeds considerably the extent of the loss to prick. But, as soon as we have to deal with destruction of the cords of the brachial plexus, the extent of the analgesia almost equals that of the loss to light touch; and, when several posterior roots have been divided, the extent of the area insensitive to prick may actually exceed that insensitive to light touch. Thus it is evident that, whilst the unit of supply for epicritic sensibility, looked at broadly, lies in the peripheral nerves, the unit of protopathic supply lies in the posterior roots. The more nearly a peripheral nerve represents the supply of one or more posterior roots, the more definite will be the borders of the analgesia produced by dividing that nerve. The median nerve probably contains sensory fibres from the seventh and eighth cervical,

and possibly even from the sixth cervical and first dorsal. Destruction of this nerve will therefore only cut off protopathic sensibility from the comparatively insignificant area to which all the fibres from these roots run in the one nerve. On the contrary, the distribution of the external popliteal, including its lateral cutaneous branch, corresponds closely to that of the fifth lumbar root. Consequently, destruction of this nerve produces a widespread loss of sensation to prick, with an extremely well-defined border on the shin and dorsal surface of the foot.

The sensory mechanism in the peripheral nerves is thus found to consist of three systems :—

(I.) Deep sensibility, capable of answering to pressure and to the movement of parts, and even capable of producing pain under the influence of excessive pressure, or when the joint is injured. The fibres, subserving this form of sensation, run mainly with the motor nerves, and are not destroyed by division of all the sensory nerves to the skin.

(II.) Protopathic sensibility, capable of responding to painful cutaneous stimuli, and to the extremes of heat and cold. This is the great reflex system, producing a rapid widely diffused response, unaccompanied by any definite appreciation of the locality of the spot stimulated.

(III.) Epicritic sensibility, by which we gain the power of cutaneous localisation, of the discrimination of two points, and of the finer grades of temperature, called cool and warm.

Let us now pass to the consideration of the arrangement of sensation in the central nervous system. The view I shall put forward is based upon the examination of a series of cases of hæmorrhage into the spinal cord, and of injuries affecting its substance, producing what is usually known as Brown-Séquard paralysis. With these we have compared the sensory changes in syringomyelia and tabes dorsalis. Now, all these conditions demonstrate that, as soon as a sensory impulse reaches its first junction in the spinal cord, it becomes shunted into tracts devoted to the conduction of impulses, grouped in a way different from that found in the peripheral nerves. It is no longer a question of protopathic, epicritic, or deep sensibility; the tracts in the

central nervous system are devoted to the conduction of impulses concerned with pain, heat, cold, and touch.

Thus, in Brown-Séquard paralysis, motion is lost in the one limb, and all sense of pain, heat or cold, is abolished in the other. Careful examination of this loss of sensation shows that sensibility is equally lost to all forms of temperature stimulation, and that we have here to do with no such separation into extreme and intermediate degrees as exists in the peripheral nerves.

In the central nervous system, the impulses are co-ordinated and distributed, just as in the central office of a newspaper the various accounts of the same event, arriving by telephone, by tape, or by telegraph, are co-ordinated and distributed according to their subject-matter.

It has long been recognised, that the viscera are not endowed with the same sensibility as the skin, and some have even questioned whether they are sensitive at all. It is certain, from the observations of Lennander (5) and his school, that the patient shows no sign of pain when the gut is incised, or even when it is burnt; the liver is also apparently insensitive to similar injuries, and yet everyone is agreed that the parietal peritoneum is highly sensitive. We determined to attack the problem from a somewhat different point of view. When a colotomy has been performed, the upper end of the gut opens freely upon the surface, and no fæces pass into the lower portion. It is therefore possible to wash out the lower gut, and by passing a tube into its upper end to apply heat and cold to what is now an isolated loop of intestine. By choosing patients who were intelligent, and such as were not cachectic or wasted from malignant disease, we obtained the following result. Water at 40° C. and at 20° C., which seemed warm and cold respectively to the skin of the abdomen, were entirely unappreciated when applied within the walls of the gut. But ice water was at once called "cold," water at 50° C. was said to be uncomfortable, and two patients of unusual intelligence spoke of this stimulus as "hot." This sensation of heat and cold was never localised in the abdominal cavity. If the patient was asked to indicate the

position of the stimulus, he either placed his hand over the region of the navel or pointed into the air. Sometimes the sensation was said to be like cold drops on the skin in a part of the abdomen where it would have been impossible for any water to have fallen. Moreover, the strictest precautions were taken to insert the tube through a ring of mucous membrane and to surround both the tube and funnel with absorbent cotton-wool, so that no moisture could possibly escape.

These experiments are not conclusive, but they seem to show that, in some ways, the sensibility of the viscera closely resembles that which we have called protopathic. Only, the extremes of heat and cold are recognised, and localisation is so defective that the patient cannot even tell whether the cold is in or outside his abdomen.

Many of the afferent impulses from the viscera produce a reflex action without affecting consciousness. When we had passed a varying quantity of warm water into the gut, the patient complained that he wished to defæcate; a reflex peristalsis had been set up of which he was conscious, although he failed completely to recognise the stimulus by which it had been evoked. Most of the afferent impulses from the stomach and intestines probably belong to this order.

To a certain extent, we seem able to appreciate the muscular movements of an internal organ, such as the stomach or intestine, even although we cannot recognise the position in space of the part that is moved. This power is probably the equivalent of that deep sensibility which remains to a part deprived of all its cutaneous sensory nerves.

Structurally, we know that the viscera are innervated from the sympathetic system, and from a set of large afferent fibres connected with the end-organs of Pacini. The latter so closely resemble the mechanism found in muscles, tendons and joints, subserving what we have called deep sensibility, that we can assume the end-organs of Pacini to be the means by which we gain a similar power of appreciating intestinal movement.

But apart from such sensations of movement, the viscera

certainly set up afferent impulses which may affect consciousness. We have attempted to show that, however feeble these sensations may be in consequence of the defective innervation of the intestine, they produce upon consciousness an effect resembling that of a low form of protopathic sensibility. Now, one of the peculiarities of protopathic sensibility is the rapid restoration of the mechanism upon which it is based. This it shares with the sympathetic system. Moreover, when a peripheral nerve to the hand is divided, it is noticeable that the palm begins again to sweat at a time after union which coincides approximately with that of the return of protopathic sensibility. This sweating is due to the motor fibres of the sympathetic (the "autonomic fibres" of Langley) that supply the skin.

It will therefore be no adventurous guess to suppose that the system we have called protopathic in the skin is one with the afferent fibres of the sympathetic as they supply the viscera. In both cases the sensation is badly localised, radiates widely, and is frequently referred to parts other than those stimulated. Both systems are incapable of appreciating light touch, and both are insensitive to the minor degrees of heat and cold. Both regenerate with the same rapidity and completeness.

We wish, therefore, to put forward a new conception of the nature of the afferent fibres in peripheral nerves.

The whole body within and without is supplied by the protopathic system. The fibres of this system in the skin may be spoken of as somatic, those to the internal organs as visceral protopathic fibres. Thus we shall no longer speak of the afferent sympathetic system, but of the protopathic supply of the internal organs.

Another set of afferent fibres peculiarly associated with impulses of movement and pressure exist in connection with the Pacinian organs. In the body and limbs, an analogous system is found peculiarly susceptible to pressure, to the localisation of movement, and to the appreciation of position. The fibres of this system run in conjunction with the motor nerves.

In addition to these two systems, which are distributed

to all parts of the body within and without, the surface of the body only is supplied by a third system, which we have called epicritic. This endows the skin with sensibility to light touch. To the impulses conducted by this system we owe the power of localising the position of cutaneous stimuli, of discerning the doubleness of two points, and of discriminating between minor degrees of heat and cold, and other special attributes of sensation. The fibres of this system are more easily injured, and regenerate more slowly, than those of the protopathic system. They are evidently more highly developed, and approach more nearly, to the motor fibres that supply voluntary muscle, in the time required for their regeneration.

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THE CONSEQUENCES OF INJURY TO THE PERIPHERAL NERVES IN MAN.

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PREFACE.

CHAPTER 1.—NERVE SUPPLY OF THE PALM OF THE HAND.

§ 1.—Loss of Sensation after Division of the Ulnar Nerve.
§ 2.—Variation in the Extent of the Area supplied exclusively by the Ulnar Nerve.
§ 3.—Loss of Sensation after Division of the Ulnar Nerve when its Dorsal Branch remains Intact.
§ 4.—Loss of Sensation after Division of the Median Nerve.
§ 5.—Variation in the Extent of the Area supplied exclusively by the Median Nerve.
§ 6.—Loss of Sensation after Division of both Median and Ulnar Nerves.

CHAPTER 2.—RECOVERY OF SENSATION AFTER INJURY TO THE NERVES OF THE HAND.

§ 1.—General Statement of the Phenomena of Recovery.
§ 2.—Recovery after Division of Particular Nerves.
(*A*) Median Nerve.
(*B*) Ulnar Nerve.
(*C*) Median and Ulnar Nerves.
(*D*) Summary.

CHAPTER 3.—RECOVERY OF SENSATION AFTER INCOMPLETE DIVISION OF THE NERVES OF THE HAND.

CHAPTER 4.—NERVE SUPPLY OF THE FOREARM.

§ 1.—The Post-axial Half of the Forearm.
§ 2.—The Pre-axial Half of the Forearm.

CHAPTER 5.—INJURIES TO THE BRACHIAL PLEXUS.

CHAPTER 6.—LOSS OF SENSATION IN THE ARM FROM DIVISION OF POSTERIOR NERVE ROOTS.

CHAPTER 7.—NERVE SUPPLY OF THE LOWER LIMB.

§ 1.—The Sole of the Foot.
§ 2.—Loss of Sensation produced by Injury to the Nerves of the Leg.
§ 3.—The Nerve Supply of the Leg deduced from Residual Sensibility.

Chapter 8.—Deep Sensibility.
Chapter 9.—Sensations of Heat and Cold.
Chapter 10.—The Compass Test.
Chapter 11.—Hair Sensibility.
Chapter 12.—Hyperalgesia.
Chapter 13.—Changes in the Skin that follow Injury to Peripheral Nerves.
Chapter 14.—Changes in the Nails after Injury to Peripheral Nerves.
Chapter 15.—Paralysis and other Muscular Changes.
Chapter 16.—Theoretical.

Preface.

Generations of anatomists have studied the course and distribution of the peripheral nerves, until knowledge of their more obvious features has apparently reached finality. It is recognised that more can be learnt of their central connections and of the relation of the larger branches to the anterior and posterior roots. But the peripheral distribution of the nerves of the hand is regarded as one of the commonplaces of anatomy.

And yet, whenever an attempt is made to apply this knowledge to some case where one of these nerves has been divided, obvious facts remain unexplained, or accessory hypotheses must be invented to account for the apparent difficulties of each individual instance. The more carefully the condition of the affected part is examined, the less does the state of its sensibility correspond with the surgeon's expectation. After he has successfully reunited the ends of the nerve, a careful examination only adds to the bewilderment of the conscientious observer.

If, for instance, the median nerve is divided, all cutaneous sensibility is abolished over a considerable part of both the index and middle fingers. But over the palm, within the area supplied by the median nerve, sensation may be diminished only. In a similar manner, division of the ulnar nerve produces complete insensibility of the little finger and of a variable portion of the ulnar border of the palm. Cutaneous sensibility is only partially lost over the palm and that part of the ring finger usually assigned to the ulnar nerve. When the surgeon or anatomist is asked why sensation is only

changes in a year are of frequent occurrence, and letters remain unforwarded. In spite of the help of an assistant, skilled in tracing the movements of hospital patients, and in spite of the fact that compensation on an ample scale was given for travelling expenses and loss of time, many cases disappeared entirely, often at the most interesting period of recovery. This is particularly liable to occur when the median has been divided. For this injury interferes little with the grasp of the hand, and the patient is afraid to attend the hospital, lest his employer should consider him unfit for work. To meet this difficulty, we found it necessary to institute frequent Sunday sittings.

No cases are included in this paper that have not been examined by one or both of us. As far as possible, one or other of us has been present during the operation; but occasionally we have been compelled to rely on the account given by others of the condition then found. With this exception, no note has been included that is not the direct outcome of our personal observation.

Cases of nerve injury usually remain but a short time in hospital, and all the later treatment is conducted in the out-patient department. But in every instance, the observations we record were made under conditions of time and space more favourable to accurate investigation. Certain mornings in the week were specially set aside for the work, and the patients were seen, one by one, in a quiet room.

First of all, the patient was asked to give an account of the condition of the part affected and any change that he might have noticed since his last visit. The state of the skin was noted and the growth of the nails measured. The movements of the injured limb were investigated; but its electrical reactions were not tested until the end of the sitting.

During the testing of sensation, the patient's eyes were closed, and, if necessary, bandaged; he was told to call out whenever he experienced a touch, a prick, or any other sensation. No further questions were asked.

Superficial touch was tested by means of cotton-wool stroked gently across the palm. Unfortunately, this stimulus,

partially lost, the usual answer is, "Because the nerves overlap." But, if each nerve occupies the territory of the other to an extent sufficient to prevent absolute loss of sensation over so large a part of the palm, it is obvious that destruction of the ulnar nerve must cause some diminution of sensibility within the median area. This loss should vary exactly in proportion to the amount of sensation that remains over this part of the palm, after the median nerve has been destroyed. But the most careful examination of the hand fails to reveal the slightest diminution of sensation over the median half of the palm, in consequence of division of the ulnar nerve. What has always been called diminished sensibility ends sharply at a line in the axis of the ring finger.

Such want of agreement between anticipated effects and the actual results of division of a peripheral nerve pointed to a gap in our knowledge of the distribution and functions of this part of the nervous system, which we have attempted to fill.

To those who have not worked in a town like London, it may seem an easy matter to examine a case of nerve injury at regular intervals from the date of the accident up to complete recovery. But any systematic attempt to carry out such an investigation is hampered by innumerable difficulties, due solely to the conditions of life among the working population of this huge city. Firstly, the original wound may have been treated at some other hospital, or by a private practitioner. Often the state of the wound and the extent of the injury can then be inferred only from the patient's description. Again, after the nerve has been successfully reunited, he may find it more convenient to attend some other hospital; or may leave his hand entirely untreated, and thus render useless the careful investigation at the time of the injury, the exploration of the wound at the time of suture, and the observations made during his stay in hospital.

Lastly, the investigation may be brought to a sudden end by his change of dwelling. For instance, within the space of twelve months, one of our cases, a married man with a family, changed his address five times. Two or three

wrong answer. We look upon this method of recording the result of single applications interspersed among an equal number of double ones as a great addition to the practical value of this test, for, when the threshold is neared, one of the first changes is a tendency on the part of the patient to become uncertain about the nature of single stimuli. At this particular distance, every touch, whether single or double, is liable to be called two. Thus, the very appearance of this condition, usually supposed to show that the patient is untrustworthy and the observations worthless, is in itself one of the most valuable signs that the threshold for the discrimination of two points is about to be reached.

The sensation of pressure was tested by means of a pencil or some other blunt object. Care was taken to record the locality to which the stimulus was referred, verbally or by indication.

The affected parts were also tested with a tuning-fork, and for this purpose we have usually used one beating 128 double vibrations a second. This is a treacherous form of stimulation, unless the patient is intelligent and the observer constantly on his guard. Error not uncommonly arises in consequence of conduction of the vibrations from an insensitive to some sensitive part at a distance; the patient then appreciates the stimulus, but not at the spot to which the fork was applied.

Wherever it was necessary to investigate the patient's ability to appreciate the position into which a joint had been passively placed, the test was carried out as follows: He was told that the fingers affected would be moved, and that he was to imitate with the sound hand the position into which they had been placed. When the sense of passive position is perfect, an intelligent patient can carry out this movement of imitation with remarkable accuracy.

A sharp needle or a steel pin was used as the test for pain, and care was taken to differentiate between the sense of deep pressure so produced and true pain. If there was any doubt as to the sensation experienced, a painful interrupted current was used as the test, and by this means it was easy to discover whether the patient's answers were

so perfect a test over parts endowed with hair, is untrustworthy over hairless parts, unless used with extreme caution.[1] Many brands of wool, when rolled into a whisp, form so stiff a mass that deep sensibility is evoked. The untreated cotton-wool used by jewellers is excellent for our purpose. But the cotton-wool of short staple, which has been rendered absorbent by the action of potash, is too stiff to be a certain stimulus for superficial touch alone. Moreover, certain parts, even of a well-kept hand, such as the outer aspect of the thenar eminence, are relatively insensitive to superficial stimulation with cotton-wool, and over the greater part of the horny hand of a workman this stimulus may evoke no response. Cotton-wool must, for these reasons, be used with extreme care, and in every case the condition of the skin must be noted with accuracy. But we wish to call attention to another source of error produced by the roughness of a desquamating skin. Cotton-wool brushed lightly across a part in this condition may be appreciated through that form of deep sensibility, which remains intact after all cutaneous nerves have been destroyed. It would then appear as if light touch were appreciated, whereas, in reality, the sensation evoked is that of pressure.

The power of discriminating two points was tested with a pair of compasses, the ends of which had been blunted. But the method adopted differs from that in general use, and requires closer description (*vide* also p. 228). The compass points were set at a certain distance from one another; they were then applied to the part to be tested in such a way that sometimes two points, sometimes one point only, touched the skin. No questions were asked, but, before the testing began, the patient, whose eyes were closed, was told to say with every application how many points he had perceived. The stimuli followed one another in an entirely irregular order, but so that, ultimately, the patient had been touched ten times with one point, ten times with two points. Each series was recorded in such a manner that it became immediately obvious in how many cases, among the ten single and among the ten double stimuli, the patient had given a

[1] During the recovery of sensibility hair-clad parts may react in a peculiar manner (*vide* Chap. 11).

Without the cordial help of the surgical staff of the London Hospital, and of the Poplar Hospital for Accidents, this work would have been impossible.

Sir Victor Horsley has alone enabled us to complete one section of this work by the liberality with which he allowed us to examine patients, in whom he had divided the posterior roots.

To Surgeon-General Stevenson, C.B., and the surgeons in charge of the Royal Victoria Hospital, Netley, we return our thanks for permission to make use of patients injured during the South African War.

Our thanks are also due to Professor A. E. Barker for leave to examine and to publish an important case under his care at University College Hospital.

Lastly, we return our thanks to the Surgical Registrars, past and present, of the London Hospital (Mr. Lett and Mr. Russell Howard), for unfailing help in the collection of patients, who attended the hospital for nerve injuries.

Chapter 1.—Nerve Supply of the Palm of the Hand.[1]

§ 1.—*Division of the Ulnar Nerve.*

Complete division of the ulnar nerve in the forearm above the point at which the dorsal branch is given off produces the following changes in the sensibility of the hand.

Touch, prick, heat and cold are no longer appreciated over the little finger and over the ulnar border of the palm. The extent of this absolute loss of cutaneous sensation varies in each individual, and in no two cases is it exactly the same. In one extreme form it may occupy the little finger, one-half of the ring finger and more than one-third of the palm and dorsum of the hand, or sensation may only be completely lost over the little finger and ulnar border of the palm.

When the whole ulnar nerve is divided, the area of absolute loss of cutaneous sensation lies between these two extreme limits, the amount of loss varying with each

[1] For the extent of the nerve supply of the hand determined by the method of residual sensibility, *vide* p. 184.

based upon deep pressure or upon the true appreciation of pain.

When sensibility to pain has returned, the limits of the loss of the higher forms of sensation can be discovered by the following method: The point of a needle or a steel pin is dragged lightly across the skin, from normal parts towards the affected area; immediately its borders are reached the patient cries out, saying that the discomfort is greatly increased. This will be spoken of as "the line of change to prick."

Many difficulties surround the testing of sensibility to heat and cold, particularly as minor degrees of temperature play so considerable a part in our investigation. An ordinary glass test tube containing ice has been used for cold, and serves this purpose admirably. For the sake of convenience, under the somewhat difficult conditions of clinical research, we have also used glass tubes in testing for heat, for warm, and for cool. But, used for this purpose, a glass tube is open to serious objections, for, if water is heated to a temperature of 50° C., the glass wall of the tube will be considerably hotter than the contained water. Thus, a thermometer placed in the water does not register the actual temperature applied to the patient's skin. In a similar manner, it is long before hot water poured into a glass tube raises the external temperature to that of the contents, and heat abstracted from the wall of the tube by contact with the skin is only restored by slow degrees. The following precautions must be observed if glass tubes are used: The tube must be over-heated and put aside to cool to the point desired; repeated stimuli must not be made at short intervals with the same test tube, and, for this reason, it is well to have a row of tubes for use as they reach the temperature required. In some of our more delicate observations we have used silver tubes; with careful use they obviate all the difficulties inherent in glass test tubes.

We cannot close this description of the manner in which our work has been conducted, without expressing our sincere thanks to all those who have generously permitted us to make use of the patients under their care.

primary coil, then place the secondary coil at such a distance from the primary, that the current applied through the smaller electrode is easily appreciated on the normal skin. Even though it may be strong enough to contract the small muscles of the thumb, such a current will not be appreciated over the area within which sensation is lost to cotton-wool.

Sensation to temperature also undergoes a change at the same border. A test tube containing water at about 22° C., and one containing water at about 40° C., cannot be discriminated, though easily appreciated as cool or warm over the normal skin.

Thus, division of the ulnar nerve produces complete loss of sensation to pain and temperature over the little finger and over a variable extent of the palmar and dorsal surfaces of the ulnar border of the hand, rarely corresponding even approximately to the anatomical borders of the ulnar nerve. But these borders are accurately marked out by loss of light touch (cotton-wool), and of minor degrees of temperature and by inability to appreciate the interrupted current applied in a definite way.

Between the boundaries of this loss of light touch and those of complete loss of cutaneous sensibility lies a territory within which sensation is profoundly changed. The extent of this area varies in each individual case. If the intermediate zone be of considerable size, so that the condition of sensation within it is easily investigated, then it will be found that not only is all sensation abolished to light touch, to intermediate degrees of temperature, and to a certain form of interrupted current, but painful stimuli produce an effect different from that upon the normal skin. As soon as the anatomical border is transgressed towards the ulnar side, a prick may become so disagreeable that the patient immediately withdraws his hand. He complains that it causes a feeling of "pins and needles," not only at the point pricked, but also widely over the intermediate zone. Asked to localise the spot pricked, he may be able to do so, but complains that the pain produced seems to him to be spread over a large surface, or even to be in two

individual. And it is this loss of sensation only which can be recognised by pricking the hand with a pin. If one finger and a half are insensitive to a prick, the surgeon is satisfied that he has to deal with a "normal" ulnar "completely divided"; when only the little finger is insensitive, he doubts whether the nerve is completely divided, or looks upon it as abnormally distributed.

But in reality, the sensibility of the hand is disturbed over an area considerably greater than that marked out by the analgesia; and, if cotton-wool is used as the test for sensation, touches, easily felt elsewhere on the hand, will not be appreciated over the whole of that portion assigned by anatomy to the supply of the ulnar nerve. This area is bounded by a line running through the longitudinal axis of the ring finger back and front, continued on the dorsal and palmar aspects of the hand to include the greater part of its ulnar half.

The whole of this border can be marked out easily with cotton-wool, for, as soon as it is passed, the patient appreciates touches that previously caused no sensation, and, if he is intelligent and quick, the passage from the insensitive to the sensitive area is found to take place at a line which varies very little, whether the stimuli progress is an orderly series from the ulnar to the radial side of the hand, or *vice versâ*.

Thus, by using cotton-wool as a test, sensation can be shown to be lost at a line corresponding to the anatomical border of the ulnar nerve.

But there are other means of showing that sensation becomes defective at this border. If a needle or pin is dragged lightly across the skin from the sound to the affected half of the hand, the patient complains that the "feeling" it produces changes as soon as this line is passed. This line can also be marked out by an interrupted current applied in the following manner: Connect one pole of the secondary coil with a large indifferent electrode, and the other pole with a small electrode covered with wash-leather set in a handle containing a key, so that the current can be thrown in and out at will. Remove the iron core from the

places at once, such as the base of the finger and the middle of the palm. Moreover, when tested with compasses, the points cannot be distinguished as causing two sensations, even when separated from one another to the greatest extent possible within the intermediate zone. An interrupted induced current, with no iron in the circuit, cannot be appreciated within this area, but, if bare metal points are used, or if the iron core is inserted into the primary coil, the stimulus causes pain, even when the distance of the coils is adjusted to compensate for the increase of strength produced by the presence of the core.

Thus, complete division of the ulnar nerve above the dorsal branch produces the following changes:—

(1) Loss of sensation to pain, to extremes of heat and cold (ice and water at 50° C.), and to painful interrupted induced currents over an area that may vary greatly in size; sometimes it includes the little finger, the ulnar half of the ring finger, and more than one-third of the palm and dorsal surface; in other cases it is reduced to the little finger and a strip on the extreme ulnar border of the hand.

(2) The patient is unable to distinguish two widely separated compass points, or to appreciate light touch, minor degrees of temperature, and the painless interrupted current over an area occupying the little and ulnar half of the ring fingers, and that part of the palm and dorsum of the hand on the ulnar side of an axial line drawn longitudinally through the ring finger. This corresponds to the border laid down by anatomy for the supply of the ulnar nerve.

(3) The sensibility of the intermediate zone on the palm, the dorsum and the ring finger may be characterised by an increase in the discomfort produced by painful cutaneous stimuli, and by a wide diffusion and want of localisation in the sensation produced by a prick.

§ 2.—*Variation in the Extent of the Area supplied by the Ulnar Nerve.*

Complete division of the ulnar nerve produces loss of sensation to light touch over the whole of the little finger

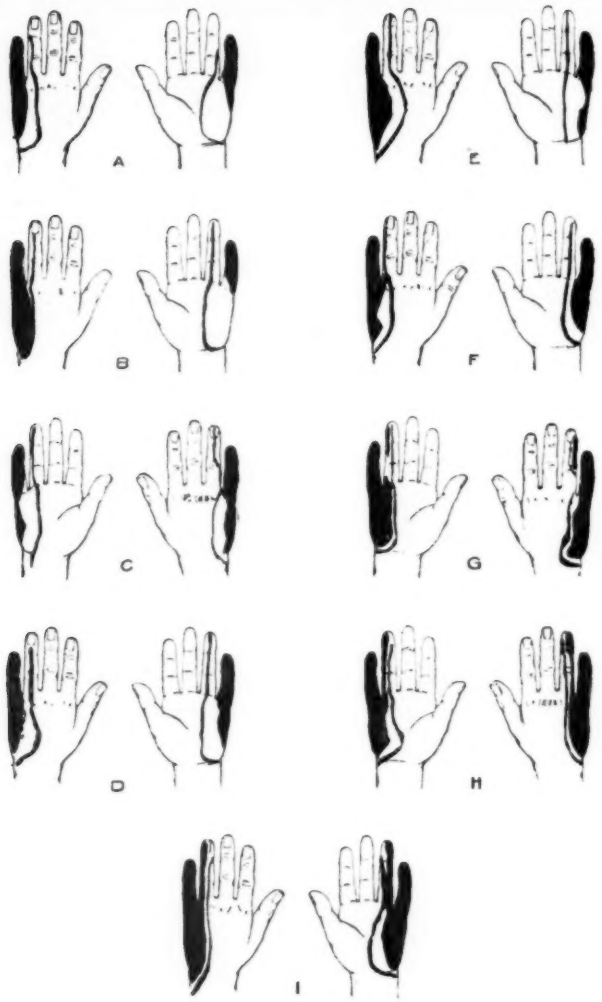


FIG. 1.

To show the loss of sensation produced by complete division of the ulnar nerve. Loss of all forms of cutaneous sensibility is represented by the black area. The parts insensitive to light touch and to the intermediate degrees of heat and cold are enclosed within the black line.

Most of these cases will be found on Table II., p. 156.

A is the loss of sensation in Case 18; B, Case 17; E, Case 16; F, Case 14; G, Case 15; I, Case 19 (also reported in full in the Appendix, p. 309). The case from which C was taken (No. 83) will be found reported on p. 311; that where the loss of sensation was represented by H, on p. 316 (No. 63). D was taken from a man in whom the ulnar nerve had been divided; secondary suture was performed, and he was not seen again until complete recovery had occurred.

and over some part of the ring finger back and front. In no instance was the sensibility of the ring finger to light touch entirely unaffected. Of nine cases in which the nerve was proved at the operation to have been divided, this anæsthesia occupied the ulnar half of the ring finger in six, and this may therefore be taken to represent the usual supply.

On the palm, the loss of sensation to light touch may occupy a border directly continuous with the axis of the ring finger, or may swing out as far as a line drawn from the cleft between the middle and ring fingers (fig. 1).

Out of these nine cases loss of light touch occupied half the dorsal surface of the ring finger in six; in one, a third of this finger was affected. In one instance, this anæsthesia occupied two-thirds of the ring finger.

On the back of the hand, the border of the area insensitive to light touch usually follows a line continuous with the axis of the ring finger, but in two cases it swung out to the radial side to reach the tendon of the middle finger.[1]

The ulnar nerve is usually divided by a transverse cut in the neighbourhood of the wrist, which must also sever some of the branches of the internal cutaneous nerve descending to supply the hand. Thus, in most cases, the scar bounds the upper or central border of loss to light touch, and it is only where the ulnar nerve has been injured at the elbow, or high in the forearm, that the true upper limit of the ulnar supply can be determined. Six such cases have come under our notice, in four of which this upper limit ran round the wrist at the level of the styloid process, and in two it formed a curved line about 1 cm. on the distal side of this point. Evidently, as far as light touch is concerned, division of fibres of the internal cutaneous nerve plays little part in the form usually assumed by this border after division of the ulnar nerve at the wrist, excepting when the anæsthesia is bounded definitely by the scar.

Thus, the extent of the loss of light touch produced by division of the ulnar nerve seems to be remarkably constant,

[1] Under certain circumstances the presence of hairs on the dorsal surface of the hand may make the determination of this border untrustworthy unless the hand be shaved (*vide* p. 239).

and it varies, if at all, only within small limits. The borders of this area are definite; it does not merge gradually, but passes abruptly into parts of normal sensibility.

The area of insensibility to pain, produced by division of the ulnar nerve, differs fundamentally in every characteristic from the condition of parts insensitive to light touch. For, not only is the extent of the loss of sensation subject to great variation, but the difficulty in determining the amount of this variation is increased by the indefinite nature of the borders of the analgesic area. At no point can it be said that here loss to pain begins; complete sensibility to pain merges gradually into complete insensibility with no sharp dividing line, and all attempts to mark out circumscribed areas of analgesia are therefore unsatisfactory. But, taking into account solely the area of total loss of sensation to prick, the only certain result of complete division of the ulnar nerve is to produce analgesia over the little finger and ulnar border of the hand. None of our cases failed to show at least so much loss to prick. But, in extreme instances, sensation to prick may also be lost over the ulnar half of the ring finger and over an area on the palm and dorsum of the hand almost co-terminous with the full ulnar loss of sensation to light touch. It is in such cases that the surgeon, using a pin as his test for sensibility, finds that loss of sensation occupies exactly the area he expected.

Between these two extremes, every form of variation exists; in no two cases is the extent of the complete analgesia exactly the same, and so diverse are the forms assumed by this loss of sensation that no form can be said even approximately to represent the normal. We have therefore represented the extent of the loss, in each case, in the form of a series of diagrams, from which it will be seen how great may be the variation (fig. 1).

Apparently, the extent of the area insensitive to light touch, and that of the area of absolute loss of sensation to prick, vary independently of one another. A large extent of the ulnar half of the hand may be entirely insensitive to pain, and yet the extent of loss to light touch in no way exceeds that found when the analgesia was confined to the little finger.

For this reason, the extent of the intervening zone of defective sensibility varies greatly. Its characteristics are an imperfect discrimination of two compass points and an inability to transmit light touch and degrees of temperature between about 22° C. and 40° C. It is, however, sensitive to pain, to ice, and to temperatures above 45° C. But, in consequence of the ill-defined borders of this total loss of sensation, the intermediate zone may sometimes be an area of very defective sensibility, or it may be sufficiently large and sensitive for careful and certain examination of its sensory peculiarities.

§ 3.—*Loss of Sensation produced by Division of the Ulnar Nerve, when its Dorsal Branch remains Intact.*

When the ulnar nerve is divided at the wrist, its dorsal branch not uncommonly escapes uninjured. Such an accident makes it possible to determine the extent to which each of the two branches supplies the ulnar area of the hand.

FIG. 2.

To show the loss of sensation produced by division of the ulnar nerve below its dorsal branch. The area of total loss of cutaneous sensibility is marked in black. The parts insensitive to light touch and to the intermediate degrees of heat and cold are enclosed within a black line.

Both these cases will be found on Table II., p. 158. A represents the loss of sensation in Case 20; B the loss of sensation which preceded and immediately followed secondary suture in Case 24.

When the dorsal branch is intact, the border of loss to light touch coincides on the palm with that found after complete division of the ulnar nerve. The whole palmar surface of the little finger and the greater part of the ulnar half of the ring finger are insensitive to cotton-wool. On the dorsum of the hand, the loss of sensation may occupy

the ulnar half of the two terminal phalanges of the ring, and the whole of the two terminal phalanges of the little finger; or the whole little finger and a small portion of the ulnar border of the dorsal surface of the hand may be insensitive to light touch. But, wherever it may be situated in any individual case, the border separating the loss of sensation on the palm, from the normal area on the back of the hand, is an indefinite one. Previously, whenever loss of light touch has been under discussion, the borders of such loss have been spoken of as lines. That is to say, the passage, from a part over which cotton-wool is appreciated to one where it no longer produces any sensation, is so rapid, that for practical purposes it may be represented by a line. This is not the case when the dorsal branch of the ulnar nerve has remained intact. The ulnar portion of the palm of the hand is insensitive to cotton-wool; but, as the stimulus progresses towards the dorsal surface, the point at which it first evokes a sensation is uncertain, and the area of anæsthesia seems to merge gradually into the complete sensibility of the back of the hand.

The extent to which sensation to prick and to the extremes of heat and cold is lost seems to vary greatly. It may be that the only absolute loss of sensation is found over the terminal two phalanges of the little finger on the palmar aspect, and over the terminal phalanx behind; or the whole ulnar third of the palm, the whole palmar surface of the little finger and its two terminal phalanges on the dorsal surface may be entirely insensitive.

This absolute loss of sensation, however extensive it may be, merges gradually into the area of partial loss and is not constant. Like all parts where sensation to prick and to the extremes of heat and cold is defective, the extent of the loss varies according to the temperature of the hand and the general condition of the patient. Thus in Case 24 (Table II., fig. 2, B, p. 130), the sensibility improved and again deteriorated, although the two ends of the divided nerve remained effectively separated.

In most cases, where the dorsal branch is intact, the considerable extent to which the borders of loss to light touch

and to prick are separated from one another, renders it particularly easy to determine the character of sensation obtained from the intermediate zone. When pricked, the patient withdraws his hand with an exclamation, as soon as the area is reached where light touch is lost. Ice and water at 50° C. can be appreciated, water between about 22° and 40° cause a sensation of touch only. But, even though a prick can be perceived, it produces a widely diffused, tingling sensation, and two compass points are not distinguished, even when separated for a distance of 4 cm.

The dorsal branch seems to supply sensibility to light touch to the lower half of the ring finger on its ulnar aspect, and to the greater part of the ulnar third of the back of the hand. If it remains intact, there may be no loss of sensation to prick on the palm or first and second phalanges of the little finger after division of the ulnar nerve. Or the extent of the area supplied by the dorsal branch may be so small that all sensation is lost over the ulnar palm, and the analgesia occupies the two terminal phalanges of the little finger, and even laps slightly on to the dorsal surface of the hand.

Thus, it would seem that the part played by the two main branches of the ulnar nerve in supplying sensation of light touch to the hand varies little, but the border between the areas they supply, unlike any touch border yet described, is not fixed; the parts, where sensation is lost to light touch, merge gradually into the back of the hand, where sensation is unaffected. But there is great individual variation in the extent to which sensation to prick and to the profounder degrees of heat and cold is lost. No two cases are exactly alike, and any focus of absolute analgesia that exists is surrounded by a wide area of partial loss to prick.

§ 4.—*Division of the Median Nerve.*

Usually, when the median nerve is divided, the skin over the dorsal and palmar surfaces of the two terminal phalanges of the middle and index fingers becomes insensitive to light touch, pain and temperature. But cutaneous sensibility

may also be lost over a wider area. The palmar aspect of the thumb, the hypothenar eminence and the greater part of the median half of the palm may be completely insensitive to prick. In such cases, the loss of all forms of cutaneous sensation nearly corresponds to the area assigned by anatomy to the supply of the median nerve. But so great a loss is not present in the majority of cases. The extent to which the palm and the palmar aspect of the thumb are affected varies greatly; but on the dorsal surface of the index and middle fingers, the boundaries of the analgesia are remarkably constant, reaching as a rule to the folds of the skin over the first interphalangeal joint of both fingers.

The extent to which sensation to pain and to temperature is completely lost varies greatly and cannot be said to be exactly similar in any two cases. But the area over which light touch cannot be appreciated is more constant. Its borders usually extend from the radial edge of the thumb-nail along the radial border of the thumb to the fold at the base of the thenar eminence; thence it passes up the great central line of the palm to the cleft between the middle and ring fingers. It includes a variable portion of the radial half of the palmar surface of the ring finger and on the dorsal surface the radial third of the terminal two phalanges of the ring finger, and the skin over the terminal two and a half phalanges of the middle and index fingers. From the radial side of the index finger the border slopes towards the thumb, running along the extreme free edge of the first interosseous space, and thence extends up the thumb, to end at the ulnar border of the nail. The area, over which light touch is lost, corresponds on the palm almost exactly with that assigned by anatomy to the median nerve.

Although cotton-wool is the best means of marking out this border, light touch is not the only form of sensation which there undergoes a change. Temperatures between about 22° C. and 40° C. are entirely unperceived as soon as this line is passed, and the painless interrupted current, generated with no iron in the circuit, ceases at this border to cause sensation, though well appreciated on the normal skin.

Thus, after division of the median nerve, exactly as with the ulnar nerve, an intermediate zone makes its appearance between the boundary for loss of light touch and the boundary of those parts over which sensation is absent to prick. Closer examination of this intermediate zone shows that sensation, produced by stimuli applied within it, has the same characteristics as that from the similar area, caused by division of the ulnar nerve. A prick usually causes pain more disagreeable in character than that of the normal skin. The patient has an urgent desire to withdraw his hand and cries out, or shows some obvious sign of discomfort. The sensation produced is widely diffused and badly localised; it is said to be a "numb-tingling pain." So characteristic may be this form of sensation, that the border at which light touch ceases to be perceived can be frequently marked out by dragging the point of a pin lightly across the skin from normal to abnormal parts, noting at what point the character of the sensation so produced undergoes a change.

Temperatures between about 22° C. and 40° C. are unperceived when applied within this area; but the more extreme degrees of cold and of heat are usually well appreciated, although they cause a diffuse, badly localised, tingling sensation, unlike any effect produced upon the normal skin.

§ 5.—*Variation in the Extent of the Area supplied by the Median Nerve.*

Among the twelve cases, where the median nerve proved at the operation to have been divided, there was but little variation in the extent of loss of sensation to light touch and minor degrees of temperature. In all, the ring finger was affected to a greater or less degree, usually one-half (six cases) or one-third (three cases) being anæsthetic; but in two instances, the anæsthesia occupied a small portion only of its extreme radial aspect, and in one two-thirds of the whole finger. On the palm, the border may vary between a line drawn through the axis of the middle, and one drawn through the axis of the ring finger. The small variations which occur on the dorsal surface, in the extent

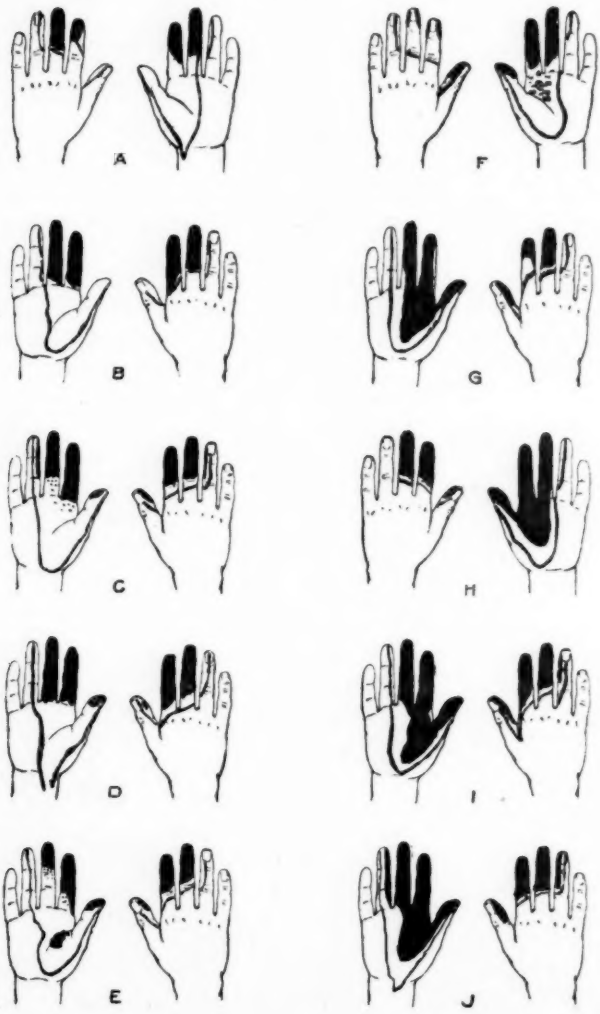
to which the index and middle fingers are insensitive, can be best appreciated from the series of diagrams on fig. 3. The greatest variation occurs on the middle finger, where the anæsthesia may extend over the two terminal phalanges or may occupy the whole finger to the base. Thus, the extent of the loss of sensation to light touch, and to minor degrees of temperature, is remarkably constant and varies within small limits.

These differences are trivial compared with the wide variations in the extent of the loss of sensation to prick, variations so profound that no two instances can be said to resemble one another exactly. In estimating the extent of this analgesia, it is important to use cases only in which the nerve was proved by operation to have been divided, and to choose only such observations as were made as soon as possible after the occurrence of the injury, before recovery could have begun.

Twelve of our cases come up to this standard. Among them five showed so large an amount of loss of sensation to prick, that the whole of the palm usually assigned to the median nerve, together with the palmar aspect of the thumb and both index and middle fingers, was analgesic. In fig. 3, L, the loss of sensation to prick on the palm was somewhat less extensive, but one-third of the ring finger was analgesic. In every case, the extent of this loss of sensation was different, until in fig. 3, A, it reached the smallest proportions we have yet seen. Here, scarcely the terminal two phalanges of the index and middle fingers were affected, and prick could be appreciated over the whole of the palm of the hand and over the palmar aspect of the thumb.

Thus, it is impossible to lay down any general rule, even with regard to the usual extent and distribution of loss of sensation to prick when the median nerve has been divided. We can only say, that, when it reached its widest extent, it almost corresponded to the area of loss of sensation to light touch, or, when the analgesia was reduced to its smallest proportions, scarcely the whole of the terminal two phalanges of the index and middle fingers were rendered insensitive to prick. Between these two extremes, every variety may occur.

It might be supposed, that the presence of a considerable area of loss of sensation to prick on the palm depended upon injury to the descending branches of the external cutaneous



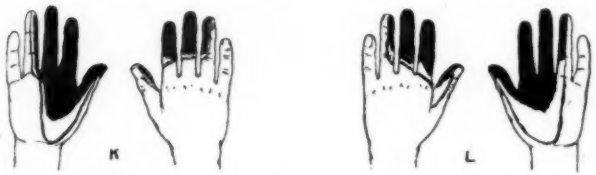


FIG. 3.

To show the loss of sensation produced by division of the median nerve. The area of complete cutaneous insensibility is marked in black. The parts insensitive to light touch and to the intermediate degrees of temperature are enclosed within a line.

Most of these cases will be found on Table I., p. 152.

A represents the loss of sensation in Case 7; B, Case 11; C, Case 13; D, Case 6; E, Case 3; F, Case 12; G, Case 8; H, Case 4; I, Case 9; J, Case 10; L, Case 5. K is taken from a woman who completely divided her median nerve in the neighbourhood of the elbow. We examined her on several occasions, but she disappeared before recovery of sensation began.

nerve. But in the patient from whom fig. 3, K, was taken the nerve was divided by a wound in the fold of the elbow. Moreover, in fig. 3, L, the extent of the analgesia was larger than in any other instance that has come under our notice, and yet the nerve had been divided through a small punctured wound at the wrist, which could not have injured any considerable number of fibres of the external cutaneous.

§ 6.—*Division of both Median and Ulnar Nerves.*

An extensive wound of the wrist may divide both the median and the ulnar nerves, causing paralysis of all the intrinsic muscles of the hand and widespread loss of sensation. To produce such great destruction the wound must be unusually severe, and, commonly, one or other nerve, though injured, escapes complete division. This is the condition in the majority of those cases where the median and ulnar nerves are supposed to have been divided. But amongst our patients were two in whom both nerves were seen to be cut across at the time of the original wound, and one, where they were divided seven weeks after the original injury for the purpose of secondary suture.

Taken in connection with a number of cases where both nerves were gravely injured, this material, though small, is sufficient to determine the extent to which light touch is

affected when the two nerves are completely divided. But the loss of sensation to prick varied so greatly in the three instances of undoubted division, that it is impossible to say to what extent this form of sensation is most commonly lost.

Sensation to light touch is abolished by this injury over the whole palm and over the palmar aspect of the thumb and all the fingers. The outline of this area on the thumb corresponds, when uncomplicated by injury of other branches, to the similar border produced by division of the median nerve, and, like it, varies in the extent to which the thenar

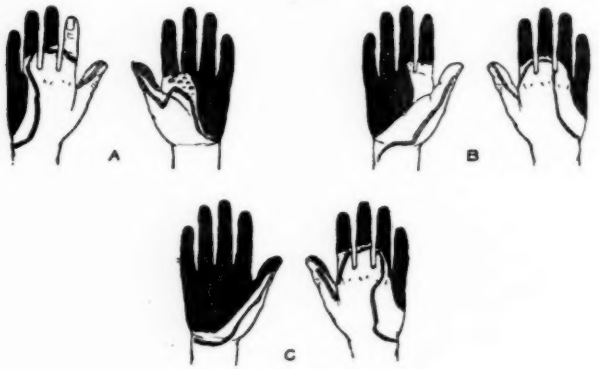


FIG. 4.

To show the loss of sensation produced by complete division of both median and ulnar nerves. The area of complete cutaneous insensibility is marked in black. The parts insensitive to light touch and to the intermediate degrees of temperature are enclosed within a line.

These cases will be found on Table III., p. 160.

A shows the loss of sensation in Case 26, B in Case 28, and C in Case 25.

eminence is involved. Sometimes the anæsthesia over the proximal part of the base of the thumb is too extensive to be due entirely to destruction of the median nerve, and is probably caused by division of fibres from the external cutaneous descending on to the palm. Any cut, running across the wrist from side to side completely, must tend to divide these branches.

On the posterior surface, the border of the area over which light touch and minor degrees of temperature are

lost varies, according to whether the dorsal branch of the ulnar nerve has been severed or not. In the three cases of complete division of both main trunks, the ulnar nerve had been divided above the point at which this branch was given off. The loss of sensation on the back of the hand, therefore, corresponded to that seen after complete division of the ulnar nerve. On the dorsal surface of the index and middle fingers, the anæsthesia extended to the proximal fold over the first interphalangeal joint in two cases, and to a point half-way between this fold and the knuckle in the third. On the thumb, the border ran from the ulnar aspect of the base of the nail to the dorsal aspect of the free edge of the first interosseous space. Thence it passed up the radial aspect of the base of the index to join the line on the dorsum of this finger.

The extent to which light touch and the minor degrees of temperature were lost corresponded exactly to the loss of sensation produced by division of the ulnar nerve, added to that caused by division of the median. Occasionally, the loss on the palmar aspect of the thumb was a little increased by destruction of branches of the external cutaneous running downwards over the wrist.

To prick, the loss of sensation varied so greatly that an attempt to describe in detail its boundaries in each case would be wearisome, and the reader is referred to fig. 4. The greatest loss appeared in Case 25 (fig. 4, c), where the whole palm and palmar aspect of the thumb were insensitive to prick. But it must be remembered that, in this patient, all the structures on the front of the wrist had been divided to the bone, and amongst them must have been included the descending branches of the external cutaneous nerve. In both the other cases, loss of sensation to prick was less extensive on the palm (fig. 4), and they probably belonged to the group in which the median nerve supplies exclusively the fingers only.

On the dorsal surface, the index, middle and ring fingers were insensitive from the tip to the lowest fold over the first interphalangeal joint in two of the cases; in one, the dorsum of the index seemed to be sensitive to prick. In all,

the whole of the little finger and a varying portion of the ulnar aspect of the dorsum of the hand were analgesic. The material at our disposal is small; but it would seem that division of the median and ulnar nerves tends to produce the following results:—

(1) Sensation to light touch is lost over the whole of the palm. Loss of sensation on the back of the fingers extends at least to the first interphalangeal joint; and if the ulnar nerve has been divided above its dorsal branch, the anæsthesia invades the whole of the ulnar half of the middle finger, the whole little finger, and a variable extent of the dorsal surface of the hand.

(2) The loss of sensation to prick varies greatly in extent. In one instance, the whole palm was insensitive to prick. In the remainder, the thenar eminence and the extreme radial portion of the hand were sensitive to this form of stimulation. On the dorsal surface, the index, middle, ring, and little fingers became analgesic over an area which varied in each case (fig. 4).

Chapter 2.—Recovery of Sensation after Division of the Nerves of the Hand.

§ 1.—*General Statement of the Phenomena of Recovery.*

The ultimate consequences of division of one of the nerves of the hand depend entirely upon the treatment adopted. If the nerve be sutured, and the wound heal by first intention, sensation may return to a condition indistinguishable from that of the normal skin. And in the progress of such return, the hand will pass through stages that throw much light on the structure and functions of peripheral nerves.

Division of the nerve leads at once to the production of an area of absolute cutaneous insensibility, surrounded by an area of loss of sensation to stimuli, such as light touch and the minor degrees of temperature. The relative extent of these two areas differs greatly in each individual case, and the first definite sign of recovery is shown by an increase in size of the intermediate zone between them. At the end of a variable period after division of the nerve, the analgesia

begins to retreat from the palm of the hand and occupies the fingers only. Gradually, it passes up the fingers joint by joint, until at last there is no part of the hand or of the fingers, where prick cannot be appreciated. During the whole of this period, the area of loss of light touch remains as well defined as on the day of the accident; it takes no part in the recovery of sensation, and yet, at the end of several months, the whole of that part of the hand supplied by the affected nerve has become sensitive to painful stimulation.

Even pressure with blunt objects, such as a pencil or the head of a pin, causes pain, and the patient complains that an accidental knock over this part of the hand is extremely unpleasant. In quality, the sensation from the affected half of the hand resembles that of the intermediate zone, which was found between the border for light touch and the border for prick shortly after the accident. Light touch is entirely unperceived, and two points of the compasses cannot be discriminated, even when widely separated. A prick causes a diffused sensation of "pins and needles," or "tingling," which is localised, not only at the point of application of the stimulus, but widely over the affected part of the hand. A test tube containing water at any temperature below 20° C. is appreciated as cold, and it matters little whether it contain ice or water at 18° C., both are said to be "ice cold." Water at 50° C. causes a stinging, corresponding to the unpleasant aspect of the sensation produced on the normal hand by too hot water. This may or may not be accompanied by a true sensation of heat, according to the stage of recovery reached by the affected hand. But whether true heat be present or not, patients usually speak of the "stinging" produced by water at 50° C. as "hot" or "burning," because no other common natural stimulus is capable of causing this peculiar, unpleasant sensation.

In the earlier period of recovery, whilst the analgesia is retreating from the hand, all sensation of true heat is, not infrequently, absent. The recovering parts are sensitive to cold and to the unpleasant "burning" or "stinging" aspect of a hot stimulus, but not to heat itself. Sensations of cold

play, therefore, a greater part in the effect produced by this area of the skin upon consciousness, and this part of the hand always "feels colder" than normal. Ultimately, however, temperatures of 50° C., or above, can be appreciated without hesitation as heat. Yet, throughout this stage of recovery, so long as light touch is completely absent over the affected area, water at 40° C. and below produces no sensation of warmth; it cannot be distinguished from water at 25° C., and is said to be neither hot nor cold.

Thus, when the whole portion of the hand affected has become sensitive to prick, the sensations evoked closely resemble those arising from the intermediate zone in their diffuseness and want of strict localisation, and in the fact that degrees of temperature between about 25° C. and 40° C. cannot be appreciated.

But, although sensation from the whole affected parts of the hand closely resembles in quality that of the intermediate zone present immediately after the nerve has been divided, yet, in intensity and rapidity of reaction, the sensitiveness of the recovering parts is considerably greater. We have no satisfactory measure of the intensity of pain, and can judge only by the statement and behaviour of the patient. By such standards it is certain, that a prick now produces a more unpleasant sensation over the same parts than shortly after the accident, before recovery could have begun. Moreover, cold and heat are felt with greater promptitude over the recovering area of the hand than over the intermediate zone between the touch and prick borders. Thus, although the quality of the sensation that can be evoked from those parts of the hand where sensibility to prick has returned, closely resembles that of the intermediate zone, the intensity, and, therefore, the extent of the innervation, has considerably increased.

At the close of this stage of recovery, all analgesia has disappeared, leaving the affected part of the hand in a condition of sensibility, with the following characteristics. Light touch cannot be appreciated. Two compass points, even widely separated, cannot be discriminated. Sensation is lost to temperatures between about 25° C. and 40° C.

Prick causes a widely diffused and peculiarly disagreeable sensation, and temperatures below 20° C. uniformly produce a sensation of ice cold, irrespective of the degree of cold registered by the thermometer. A stimulus between 45° C. and 50° C. will, when recovery is well advanced, be perceived in most cases as warmth, but above 50° C. it will be called "hot," even in the earlier stages of recovery, on account of the "stinging" it produces, whether true temperature sensation be present or not.

In this condition, the affected parts of the hand may remain for several months. Then, if the nerve has healed well, the border for loss of light touch is found to be no longer so definite as before. At first, that portion nearest to the wrist loses its sharpness and distinctness; then the boundary on the palm or on the dorsum of the hand becomes indefinite. Gradually the whole palm and, in the case of the ulnar nerve, the back of the hand becomes sensitive to light touch, the fingers alone remaining anæsthetic. At last, even the fingers regain their sensibility to light touch. One of the earliest signs of return of this form of sensation is the power of discriminating intermediate degrees of temperature.

As soon as light touch begins to be appreciated over the affected parts, water from about 35° C. to 40° C. again produces a sensation of warmth, and any two temperatures between 25° C. and 40° C. can be discriminated, the one being said to be warmer or cooler than the other.

Month by month, the sensation caused by painful stimuli grows less and less diffused and loses its tingling character. Month by month, the power of distinguishing between two compass points improves. But, if the nerve has been completely severed, the sensibility of the parts does not as a rule become normal for more than two years. The old border for loss to touch can still be marked out by a change in the character of the sensation produced by cotton-wool, a change consisting in diminution of intensity and wide diffusion from the point stimulated. An even better method of marking out this border is to drag a pin lightly across the palm from normal to affected parts. At the original line of

loss of touch the point becomes more painful, and the pain produced is widely diffused. This change in quality remains many months after sensibility to light touch has been restored to all the affected parts of the hand.

Under favourable conditions, even these differences may disappear, and the sensibility of the affected area may become indistinguishable from that of the normal skin.

Should the wound have suppurated, or the nerve have been left unsutured, sensation may still return by the same stages, but the time of restitution will be prolonged. Whenever healing of the nerve is rendered less easy by want of apposition of the divided ends, or by unfavourable conditions in the wound, such as suppuration, the final recovery of sensation may be incomplete.

But the power of recovery possessed by a sensory nerve, even under the most unfavourable conditions, is remarkable.

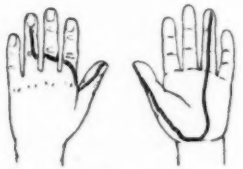


FIG. 5.

To show the area insensitive to cotton-wool and to intermediate degrees of heat and cold in Case 1. The whole hand was sensitive to prick and to the more extreme degrees of temperature.

We collected the names of all those who had been admitted to the London Hospital for injury to some peripheral nerve between the years 1892 and 1902. Several of these persons could not be traced, but many presented themselves, and were examined by us. Among them were fourteen cases where there was reason to suppose that the ulnar nerve had been divided, and eight of division of the median nerve. Out of these twenty-two patients, fourteen had recovered sensation so completely, that no difference could be discovered between the two hands. In one man, where primary suture had been performed four years before he came under our observation, no recovery had apparently taken place. He

was watched for a time, and, as no improvement occurred, further operation was suggested; from that time he disappeared. But, although our observations are here incomplete, we can at any rate state with certainty that in rare cases no material recovery may take place within four years.

Recovery may be arrested at the end of the first stage, leaving the hand sensitive to pain and to the more extreme degrees of heat and cold, but insensitive to light touch. Such cases must be uncommon; we have seen only one.

Case 1.—*Complete absence of sensation to light touch and minor degrees of temperature, more than three years after primary suture of the median nerve, in spite of restored sensibility to prick.*

On December 31, 1898, Henry S. cut his left wrist with a broken bottle, and came to the London Hospital at once. The tendons of the flexor sublimis, flexor carpi radialis, and palmaris longus, had been divided, and the median nerve was completely severed. The tendons and the nerve were reunited, and the wound is said to have healed by first intention.

When we first saw him in February, 1902, he said that his hand only troubled him in cold weather. The abductor and opponens pollicis acted voluntarily, and reacted to an interrupted current. Cotton-wool was not appreciated over the area shown in fig. 5, and within these limits he was insensitive to temperatures between 20° C. and 40° C. Even 45° C. was rarely said to be anything but a touch. Yet ice and water at 50° C. were everywhere called cold and hot correctly. Nowhere over the median half of the palm could the two points of the compasses be discriminated, even when they were separated to a distance of 2 cm., although, on the normal hand, he made no mistakes when they were 1 cm. apart.

The whole of this area was sensitive to the prick of a needle, and the sensation so caused was not only more disagreeable than over the normal parts, but was widely diffused, "running about the hand." The borders of that part of the hand supplied by the median nerve could be marked out, by noting the points at which a needle dragged across the palm began to cause this curious diffused sensation.

If the hand becomes sensitive to prick, light touch will ultimately be appreciated over the affected parts;[1] but this

[1] To this rule we have seen one exception only (Case 1, quoted above).

restoration is not uncommonly incomplete. Any stimulus then causes a sensation which differs from that produced over normal parts in its diffuseness. Should the stimulus be of such a nature that it evokes pain, this pain will become a more prominent feature, and when a pin is dragged lightly across the skin, the patient withdraws his hand as soon as the border of the affected area is crossed, saying that it is more painful than over normal parts. Out of twenty-three cases, seven still showed this line of changed sensibility five years after the injury, and it was well marked in an old man whose ulnar nerve had been divided fifty-nine years before he came under our notice.

Whenever this line of change is present, the balance has not been re-established between that form of sensation evoked by a prick and that sensibility which responds to light touch. Light touch and the intermediate degrees of temperature can be appreciated. But, as the sensitiveness to these stimuli is less than normal, the diffuse and disagreeable characteristics of the earlier form of sensibility still intrude themselves, even with stimuli that are not painful over the normal skin. Whenever this line of change is well marked, the power of discriminating two compass points will be found to be diminished, a sign that the highest forms of sensation have not yet completely returned.

Case 2.—To show how the character of the sensibility of affected parts may remain changed six years after division of the median nerve, in spite of return of sensation to light touch.

In 1897, G. R. P. cut his left wrist with broken glass, and the wound was stitched at once without an anæsthetic. Sensation was completely lost, according to his account, over the index and middle fingers, and was changed in the palm. When we saw him in February, 1903, he complained that "although I can feel, I cannot define what I touch." He was a medical student, and daily noticed this inability of the left hand. He could not use his left hand for palpation, and if he was told to feel resistance in the abdomen he could not localise it, although he could appreciate the pressure against his hand. He complained that, in cold weather, the index and middle middle fingers became almost powerless.

The outer thenar group of muscles (abductor and opponens pollicis) were wasted, but both muscles acted voluntarily and reacted to the interrupted current.

The whole hand was sensitive to light touch with cotton-wool, to the prick of a pin, and to temperatures of 22° C. and 38° C. But, if a pin was dragged across the palm from the ulnar towards the radial aspect, the sensation changed profoundly at a line corresponding to the border of the median area. On the radial side of this line, the point caused a sensation which spread widely, and produced tingling in the fingers. When the stimulus was repeated, he had an irresistible desire to scratch the part affected.

Over this area, on the radial half of the hand, he made two mistakes in ten stimulations with the compass points at 2 cm. At 1·5 cm., applied transversely, the mistakes were more numerous ($\frac{1}{2}\frac{6\text{ R. }4\text{ W}}{7\text{ R. }3\text{ W}}$). But, on a similar part of the sound hand, his answers were perfect when the compass points were separated for not more than 0·75 cm.

In order that this line of change may make its appearance in its characteristic form, the parts affected must have been sensitive for a considerable period during recovery to pain and to the more extreme forms of temperature alone. Then, the old boundary for loss of light touch will be marked by a change in the character of the sensation, for many months after the whole hand has become sensitive to all forms of cutaneous stimulation. But, whenever the two forms of sensation have been restored *pari passu*, this line of change cannot be discovered.

No material part in this return of sensation to light touch can be attributed to overlapping fibres from the uninjured nerve trunk. For a comparison of the extent of the area insensitive to this stimulus produced by complete division of the ulnar or of the median nerve shows, that they must overlap one another to a slight amount only. Out of the nine cases where the ulnar nerve was divided, the anæsthesia occupied half the ring finger in three, one-third in three, and less than one-third in one; in two, more than one-half the ring finger was insensitive to light touch. Out of twelve cases of division of the median nerve, sensation to light touch was lost over one-half the ring finger in six, one-third in three, over less than a third in two, and over

more than one-half in one instance. In no case, where either nerve was proved to have been divided, was the ring finger entirely unaffected. Thus, on the ring finger at any rate, the overlapping must be at most one-third of the breadth of the finger.

On the palm, the area insensitive to light touch has an outline which varies in each case. But here also the evidence points to no considerable overlapping between the supply of the median and ulnar nerves, as far as sensation to light touch is concerned.

The remarkable length of time required for the return of this form of sensation after complete division of the nerve, and the extraordinary fixity of the boundaries of the anæsthesia, all show that ultimate recovery is due to return of conduction, rather than to substitution by the overlapping fibres of the uninjured nerve.

But the ill-defined borders and the comparatively small extent of the total analgesia, and the fact that a large part of the palm rarely becomes insensitive to prick from a lesion of one nerve only, all point to much overlapping of the fibres that conduct pain impressions. Such overlapping should lead to rapid restoration of sensibility to prick, and in some cases possibly forms a factor when sensation returns with unusual rapidity. Commonly, no wide loss to prick on the palm follows division of the median nerve, because the fibres which conduct this form of sensation are supplied from both nerves. But, supposing the nerve supply of the median palm came overwhelmingly from the median, division of this nerve would produce at first total analgesia. This might rapidly pass away, to some extent, as soon as the few fibres of the ulnar nerve to the median palm became capable of supplying sufficient sensibility for the transmission of impulses. This certainly forms an important feature in the recovery of sensation to prick after division of the volar branch of the ulnar nerve.

Thus a girl of 17 (Case 24)[1] divided her ulnar nerve below the dorsal branch. The divided tendons and the ends of the nerve were dealt with the same day, and the wound healed

[1] Reported in full in the Appendix, p. 313.

by first intention. At first, sensation to prick was lost over a small area in the centre of the ulnar palm. This loss rapidly disappeared, leaving an area of anæsthesia to light touch over the palmar aspect of one and a half fingers and over the ulnar half of the palm. During the remainder of the summer, the condition of the hand improved, but remained stationary throughout the earlier part of the winter. Then, sensation to prick began to deteriorate, and the state of the nerve was therefore explored. At the operation an extraordinary condition was discovered, which prevented all possibility of union. The upper end of the nerve had been sutured to the divided tendon of the flexor carpi ulnaris, the lower end of the nerve to one of the tendons of the flexor sublimis digitorum. Thus, all the return of sensation to prick, which occurred during the summer months, must have been due to the innervation of the parts affected by the dorsal branch of the ulnar nerve, which had remained intact. The subsequent deterioration was probably caused by the numbing effect of the cold weather on a part sensitive only to prick and to extremes of heat and cold.

With so much overlapping of nerve supply, complete recovery of sensibility to prick might occur, without union of the divided nerve, by a further development of those fibres in the uninjured nerve which normally supply the affected parts. In areas where sensation to prick is only partially lost, such substitution undoubtedly occurs, as we have shown by the above example. But there is no evidence to show, that restoration of sensation can be produced in analgesic parts without union of the divided nerve. In one instance (Case 83), where the ulnar nerve had been operated upon repeatedly and portions removed so as effectually to prevent all chance of its reunion, sensibility to prick showed no signs of return. The fibres of the median seem to have made no attempt to encroach on the area of total analgesia, produced by the original destruction of the ulnar nerve.

Sometimes, it is necessary to divide an injured nerve, after sensibility to prick has already begun to return to the hand, that more perfect union may be obtained. Wherever

such an operation has been performed, the parts that had begun to recover sensibility became again insensitive to prick, a proof that the recovery must have been due to union, however imperfect, of the divided nerve. Impulses from the recovering parts had passed up the injured trunk, and not up one of the normal nerves. This contention is supported by the following instance (Case 11).[1]

In May, 1901, a stonemason cut his right forearm with broken glass, dividing the median nerve. So little improvement had taken place up to April, 1902, that Mr. Eve determined to explore the wound. The two ends of the nerve were found to be widely retracted, and between them lay what appeared to be a strand of connective tissue. The ends were freshened and united. After the operation the extent of the total loss of sensibility to prick had distinctly increased, showing that the slight recovery which had taken place must have been due to the strand of tissue that was found between the two ends of the divided nerve.

§ 2.—*Recovery after Division of Particular Nerves.*

When all the cases of nerve injury to the hand are massed together, certain general principles emerge clearly. But as soon as each constituent group is analysed, the number of cases becomes so small that general conclusions are overwhelmed in the special conditions surrounding each particular instance. Nevertheless, we have arranged our records in tabular form and shall now consider more in detail the manner in which sensation is restored after injury to each of the nerves supplying the hand. On these tables, the time of recovery of each of the great forms of sensation[2] is expressed in days. But it must be remembered that in many cases these dates are necessarily only approximate. A man, whose median nerve had been united, would be asked to come on a particular day. But perhaps he was at work and refused, or had changed his address and did not receive

[1] Reported in full in the Appendix, *vide* p. 304.

[2] For the significance of the terms "Protopathic" and "Epicritic" see Chap. 16.

our request, or simply did not trouble himself to obey, saying his hand was "all right." Before he could be found, or other arrangements made, several weeks might elapse. When ultimately he presented himself for examination, the particular form of sensibility, which had so nearly returned on his previous visit, would probably have been restored completely. What date are we to assign for this return? If we enter the return as complete on his previous visit, we shall have antedated it by perhaps a few days; if we say it had returned by the date of his next visit, it is certain that we shall overstate the time necessary for the restoration of this form of sensation. Thus, although all the dates are given in terms of days it must not be thought that our observations warrant any such precision; days have been adopted as our unit solely to avoid the awkwardness of fractions of a week.

(*A*) *Median Nerve.* [*Table* I.]

In six cases of primary suture, where the wound healed without complication, the period between the operation and the first return of sensation averaged 65 days.

Out of these six cases the shortest period occupied was 44 days, the longest 92. It may justly be objected, that sensibility to prick might return over large areas equally at the same time, and that the date of an obvious diminution in the size of the analgesic area does not represent the time at which recovery begins. This is probably true. The loss to prick has indefinite borders; it merges into an area of varying extent, within which sensibility to the stimulus is greatly lowered. For a time, considerable recovery might, and almost certainly does, take place without materially pushing back the border of absolute loss of sensation, return of function being confined mainly to the outlying zone of diminished sensibility. When the median nerve is divided, this is peculiarly liable to occur. For the sensibility of the median palm to prick is always somewhat lowered by such an injury, and it will depend upon the extent of this loss, whether the analgesia appears to be confined to the fingers

Case	Date of Injury	Nature of Injury	Operation and Result
No. 3, W. B. ..	Dec. 19, 1901	Glass cut of wrist. Many tendons divided. Nerve seen to be divided (H. H. and J. S.)	Primary suture, Dec. 19. Healed well
No. 4, A. C. ..	Dec. 22, 1902	Glass cut of wrist. No tendons divided. Nerve seen to be divided (J. S.)	Primary suture, Dec. 22. First intention
No. 5, T. P. ..	Oct. 2, 1902	Knife cut of wrist. No tendons divided. Nerve seen to be divided below a high branch to the thumb muscles (J. S.)	Primary suture, Oct. 4. First intention
No. 6, S H. .. [*Vide* Appendix, p. 300.]	Oct. 3, 1903	Razor cut of wrist. Many tendons divided. Nerve completely divided	Primary suture, Oct. 4. Healed well
No. 7, W. J. K.	Sept. 11, 1902	Glass cut of wrist. Many tendons divided. Nerve completely divided (J. S.)	Tendons sutured Sept. 11. Nerve sutured Sept. 19. Slight suppuration. In May, 1903, a stitch abscess was opened and the wound healed firmly
No. 8, E. E. P.	Feb. 7, 1903	Cut with coal. No tendons divided. Nerve completely divided (J. S.)	Primary suture, Feb. 9, 1903. Wound healed by granulation
No. 9, M. A. G.	Aug. 24, 1902	Glass cut of wrist. No tendons divided. Nerve completely divided (J. S.)	Primary suture, Aug. 25, 1902. Wound healed by granulation
No. 10, C. W. ..	Jan. 21, 1905	Glass cut of wrist. Palmaris longus tendon divided. Median nerve divided	Primary suture, Jan. 21, 1905. First intention
No. 11, D. J. T. [*Vide* Appendix, p. 304.]	May 6, 1901	Glass cut of forearm 3 cm. above fold of wrist. No tendons divided. At operation for secondary suture ends of nerve were found 4 cm. apart (H. H.)	Secondary suture, May 16, 1902 (375 days). First intention
No. 12, C. F. ..	Sept. 23, 1903	Cut with chisel 6 cm. above fold of wrist. Median nerve only divided (J. S.)	Secondary suture, Feb. 22, 1904 (153 days)
No. 13, P. D. ..	.. .. ..	Glass cut of wrist. No tendons divided. At secondary suture ends of median nerve were embedded in fibrous tissue. No union (J. S.)	Secondary suture, Feb. 6, 1905

Return of Sensation			Muscles
Protopathic	Epicritic	Final Result	
Began March 7, 1902 (78 days). Complete June 4, 1902 (166 days)	Began June 11, 1902 (173 days). Complete Dec. 17, 1902 (363 days)	Line of change disappeared Feb. 11, 1903 (419 days). Compasses almost perfect at 1·5 cm., June 3, 1903 (530 days)	Reacted to induced current July 2, 1902 (195 days). Voluntary movement Aug. 13, 1902 (237 days).
Began Feb. 4, 1903 (44 days). Complete July 12, 1903 (202 days)	Began Sept. 6, 1903 (258 days). Complete Nov. 18, 1903 (331 days)	Slight line of change only. Compasses perfect at 1 cm. Aug. 20, 1905 (972 days)	Voluntary movement and reaction to induced current present Sept. 30, 1903 (282 days).
Began Nov. 26, 1902 (55 days). Complete May 24, 1903 (233 days)	Began Aug. 23, 1903 (324 days). Complete Jan. 13, 1904 (468 days)	Line of change disappeared Feb. 26, 1905 (877 days). Compasses not quite perfect at 3 cm., May 6, 1905 (945 days)	No loss of power or reaction at any time.
Began March 30, 1904 (178 days). Complete April 27, 1904 (205 days)	Began July 8, 1905 (642 days)	.. ..	When first seen by us, Jan. 13, 1904, muscles acted slightly and reacted to induced current. Gradual improvement took place.
Began Nov. 26, 1902 (68 days). Remained almost stationary from Dec., 1902, to May, 1903. Completely returned July 15, 1903 (299 days)	Began July 15, 1903 (299 days). Terminal phalanges still affected, Aug. 19, 1903 (334 days)	Disappeared from observation Aug. 19, 1903, with line of change to prick, and some loss of epicritic sensibility over terminal phalanges	Acted voluntarily and reacted to induced current July 15, 1903 (299 days).
Began May 13, 1903 (92 days). Complete on Jan. 20, 1904, when he was again found	Was lost again. On Aug. 24, 1904. he showed only a line of change (560 days)	.. ..	On Aug. 23, 1905 (924 days). Abductor and opponens pollicis did not act voluntarily or react to induced current.
Began Oct. 29, 1902 (65 days)	.. ..	Disappeared from observation.	
Began March 15, 1905 (54 days). Complete June 29, 1905 (158 days).			
Began Dec. 21, 1902 (220 days). Complete Jan. 25, 1903 (254 days)	Began Jan. 31, 1904 (625 days). Complete April 10, 1904 (695 days)	Line of change still present. With compasses at 2 cm. everything called "two" (1,099 days)	Slight voluntary action and feeble reaction to induced current May 24, 1903 (373 days).
Began April 5, 1904 (42 days). Complete Aug. 28, 1904 (187 days)	Began June 18, 1905 (469 days)	.. ..	On Feb. 26, 1905 (369 days), muscles reacted to interrupted current. On June 18, 1905 (481 days), they reacted voluntarily.
Began March 8, 1905 (30 days). Complete Aug. 27, 1905 (202 days).			

or to occupy the greater part of the palm supplied by the median nerve.

If the nerve has been reunited, and the wound has healed well, the area of total loss to prick will begin to grow smaller in about 7 to 11 weeks, and the palm will then recover rapidly. Three to eight weeks later, total analgesia will be found on the fingers only; but here the skin may remain insensitive, especially over the terminal phalanges, for a considerable period. Finally, the whole of the affected area becomes sensitive to prick in about seven months, or 200 days, the average of four uncomplicated cases, in which the records are perfect, was 190 days.

We have already pointed out that the area of absolute analgesia is in some cases confined to the fingers; but, in many instances, it occupies a greater or less extent of the radial half of the palm of the hand. We believe that when absolute loss of sensation to prick is found on the palm, recovery begins at a somewhat earlier date than if this loss is confined to the fingers.

Any want of health in the wound retards recovery to a remarkable degree. In Case 7, slight suppuration took place in the original wound, which appeared ultimately to heal. Sensation began to return after 68 days; then no further recovery took place for five months. During this time, a swelling appeared on the site of the injury which was found to contain pus, evidently due to contamination of one of the deep stitches. In consequence of this deep suppuration, the return of sensation to prick was prolonged over a period of 230 days, rapid recovery following the evacuation of a small abscess.

Light touch began to be appreciated at times which varied from 173 to 324 days after suture of the nerve. Among four complete cases, the average time was 262 days. Here, again, the figures are only approximate; for, during the early stages of recovery, the condition of sensibility to light touch depends on circumstances out of the control of the observer. If the day is bright and warm and the patient in good bodily condition, cotton-wool may be appreciated faintly, but with certainty, on the palm of the

hand. A week later, in the bitter cold of early spring, the same parts may be entirely insensitive to light touch. The length of the time required before light touch (cotton-wool) could be appreciated on every part of the affected hand varied from 331 to 468 days after suture, an average in three cases of 387 days.

But this in no way completes the recovery of sensation. Long after light touch can be appreciated over the affected area, all stimuli cause a more disagreeable sensation than over normal parts. When a pin is dragged lightly across the skin, the borders of the area that was once anæsthetic can still be recognised by the change in character of the sensation produced by the point. At last, in a successful case, even this line of change disappears. We have been able to follow two cases only up to this condition; in No. 3 the line of change disappeared from the affected hand 419 days after suture of the nerve. This must be unusually early, for in No. 5, the line of change was not abolished for 877 days after the injury, and in two patients, whom we have watched for over two years, this sign of defective sensation is still present.

Whenever this line of change is present, the appreciation of two compass points is defective. One patient only recovered complete power of discriminating between two points, whilst in one it still remains defective 945 days after suture when the points are not more than 2 cm. apart.

Neither simultaneous injury to tendons nor paralysis of the muscles supplied by the median nerve have any obvious effect upon the rapidity of the return of sensation. The most satisfactory and most uniform return took place in Case 3, where the tendons were injured and muscles paralysed. In another instance (Case 5), the muscular branch was spared and no tendons were divided; but recovery occupied rather more than the average time. On Table I. are three instances of secondary suture of the median nerve. But recovery of sensation ran a course so different in the three cases, that the consideration of the effect of secondary suture will be postponed, until we have analysed the return of sensation after injury to the ulnar nerve.

(*B*) *Ulnar Nerve.* [*Table II.*]

We have been able to watch the recovery of sensation in four cases where the ulnar nerve was divided at the wrist. In three, the wound healed without complication, and sensation first began to return on an average in 109 days (92 days, 104 days, 131 days). The whole of the affected parts had become sensitive to prick in from 166 to 181 days—an average of 171 days.

TABLE II.—

(*A*) TOTAL NERVE TRUNK.

Case	Date of Injury	Nature of Injury	Operation and Result
No. 14, J. S. ..	June 26, 1903	Glass cut 6 cm. above fold of wrist. Tendon of flexor carpi ulnaris and innermost tendon of flexor sublimis divided. Nerve completely divided (J. S.)	Primary suture, June 26, 1903. Healed by healthy granulation
No. 15, E. R. ..	July 29, 1903	Glass cut 2·5 cm. above fold of wrist. Tendons of flexor carpi ulnaris and ulnar tendons of flexor sublimis divided. Nerve completely divided (J. S.)	Primary suture, July 29, 1903. Considerable suppuration. Healed by granulation
No. 16, A. P. ..	June 11, 1903	Glass cut of wrist. All tendons divided except flexor carpi radialis and radial tendons of flexor sublimis. Nerve completely divided (J. S.)	Primary suture, June 11, 1903. Wounds healed by first intention
No. 17, J. M. ..	Aug. 26, 1904	Glass cut of wrist. Flexor carpi ulnaris and ulnar nerve divided	Tendon and nerve sutured, Aug. 26, 1904
No. 18, W. W...	July 16, 1902	Glass cut of elbow. Extensor communis digitorum wounded. Ulnar nerve divided	Nerve sutured, July 31, 1902. Healed by first intention
No. 19, L. C. .. [*Vide* Appendix, p. 309.]	.. ..	Injury to elbow-joint in childhood. Bony outgrowths pressed upon nerve during his work; formation of fibroma of nerve	June 17, 1904. Resection of 4·5 cm. of nerve at elbow and suture of divided ends (J. S.)

Unfortunately, we are able to bring forward two cases only to determine the date at which sensibility to light touch returns after uncomplicated primary suture of the whole ulnar nerve. In one of these the period was 166 days, in the other 172 days—an average of 169 days or 24 weeks.

In one instance only were we able to follow the patient to complete recovery. Here the affected parts of the hand became sensitive to light touch in 278 days and the "line of change" had disappeared in 590 days; at this date he gave

ULNAR NERVE.

Return of Sensation			Muscles
Protopathic	Epicritic	Final Result	
Began Nov. 4, 1903 (131 days). Complete Dec. 9, 1903 (167 days)	Began Dec. 16, 1903 (172 days). Complete March 30, 1904 (278 days)	Line of change gone Feb. 5, 1905. Compasses perfect at 1 cm. (590 days)	Reacted to induced current Oct. 30, 1904 (492 days). Feb. 5, 1905, muscles acting perfectly (590 days).
Began Dec. 2, 1903 (127 days). Complete June 12, 1904 (320 days)	Began June 12, 1904 (320 days). Complete Aug. 27, 1905 (760 days)	Line of change present Aug. 27, 1905	June 12, 1904 (320 days), 1st dorsal interosseous and adductor pollicis acted voluntarily. First dorsal interosseous reacted to strong induced current.
Began Sept. 23, 1903 (104 days). Nearly complete when he disappeared Dec. 9, 1903 (181 days)	Recovery had not begun Dec. 9, 1903, but was complete when he was next seen, June 29, 1904 (383 days)	On August 3, 1904, line of change still present, and the compasses were badly appreciated at 2 cm. (418 days)	All muscles reacted to induced current June 29, 1904 (383 days)
Began Nov. 23, 1904 (92 days). Complete Feb. 8, 1905 (166 days)	Began Feb. 8, 1904 (166 days)	.. ..	No recovery of muscles.
Began Nov. 26, 1902 (117 days). Complete Jan. 28, 1903 (180 days)	Began May 13, 1903 (287 days). Complete Jan. 6, 1904 (525 days)	On June 18, 1905, line of change gone; compasses good at 2 cm., uniformly wrong at 1 cm. (1,053 days)	July 3, 1904 (702 days), all interossei acted and reacted to the interrupted current. Muscles acted voluntarily.
Began Sept. 14, 1904 (89 days). Complete Aug. 16, 1905 (425 days)			

TABLE II.—

(*B*) DORSAL BRANCH INTACT.

Case	Date of Injury	Nature of Injury.	Operation and Result
No. 20, A. L. ..	Jan. 25, 1903	Glass cut of wrist. Nerve divided ..	Primary suture, Jan. 26, 1903. Healed by healthy granulation
No. 21, H. E. ..	July 11, 1901	Cut of wrist with a stoneware jar. Tendon of flexor carpi ulnaris divided. Nerve completely divided (J. S.)	Primary suture, July 11, 1901. Healed by first intention
No. 22, H. W. ..	July 6, 1904	Glass cut of wrist. No tendons. Nerve divided below dorsal branch	Primary suture, July 6, 1904. Healed by granulation
No. 23, K. W. ..	Between Aug. 26-31, 1901	Glass cut of wrist. At operation for secondary suture nerve was found completely divided (H. H.)	Secondary suture, Sept. 24, 1901 (about 28 days). Healed by first intention
No. 24, E. A. .. [*Vide* Appendix p. 313.]	March 7, 1902	Glass cut of wrist. At operation for secondary suture it was found that divided nerve had been stitched to tendons (J. S.)	Secondary suture, July 22, 1903 (502 days). Healed by first intention

good answers to the compass test, even when the points were separated to 1 cm. One other patient, who had been watched for a time and then disappeared, was rediscovered 383 days after the injury; at this time he could appreciate light touch everywhere over the parts affected, but a marked line of change was present and the compass test was defective at 2 cm.

The ulnar nerve, in consequence of its exposed position at the elbow, is subject to injuries at a point at least 25 cm. distant from the wrist. This seems to make little material difference to the length of time required for the return of sensibility to prick. In No. 18, this form of sensation began

ULNAR NERVE.

Return of Sensation			Muscles
Protopathic	Epicritic	Final Result	
Had begun June 10, 1903 (135 days), and was complete Aug. 5, 1903 (192 days)	Began Sept. 16, 1903 (234 days). Complete March 23, 1904 (424 days)	On June 8, 1904, line of change still present. Compasses entirely wrong at 2 cm. (500 days)	Acted voluntarily, and reacted to induced current Dec. 9, 1903 (319 days).
Began Aug. 13, 1901 (33 days). Complete Nov. 13, 1901 (125 days)	Had not begun to return on Dec. 20, 1901	Died of malignant disease of the liver, Dec. 23, 1901	On Nov. 13, 1901, no muscles acted voluntarily or reacted to induced current.
Had already begun on Aug. 10, 1904 (35 days). Complete Sept. 28, 1904 (84 days)	Began Nov. 16, 1904 (133 days). Complete Feb. 8, 1905 (217 days)	June 21, 1905, compasses perfect at 1·5 cm.; badly appreciated at 1 cm.	Feb. 8, 1904 (217 days), 1st dorsal interosseous reacted to induced current, and showed the first traces of voluntary movement.
When seen by us there was no loss of this form of sensibility (57 days)	Began Feb. 26, 1902 (154 days). Complete June 11, 1902 (258 days)	Dec. 7, 1904, line of change present. Compasses at 2 cm. everything called "two"	Nov. 7, 1902 (408 days), 1st and 2nd dorsal interossei acted voluntarily, and all ulnar muscles reacted to induced current.
Began Dec. 2, 1903 (133 days). Complete Jan. 13, 1904 (176 days)	Began March 30, 1904 (252 days). Complete Sept. 21, 1904 (426 days)	Aug. 16, 1905, line of change present. Compasses perfect at 2 cm.; at 1·5 cm. everything called "two" (755 days)	July 27, 1904 (370 days), 1st dorsal interosseous acted voluntarily. Adductor pollicis and abductor minimi digiti reacted to induced current.

to return in 117 days, and the whole affected parts had become sensitive in 180 days. In No. 19, where a portion of the nerve had been excised at the elbow and the ends reunited, sensation began to return in 89 days, and in 425 days had returned completely.

But injury at the elbow seems to cause a material delay in the final restitution of sensibility to light touch compared with the period required, when the nerve has been wounded at the wrist. In No. 18 light touch was first appreciated 287 days after the nerve had been sutured, and the whole area affected did not become sensitive to cotton-wool for 525 days. In this instance the "line of change" did not disappear for nearly three years (1,053 days).

When the dorsal branch remains intact, it is usually difficult to determine the date at which sensibility to prick begins to return. For the area of total loss is mostly so small, and is at the same time so variable according to the temperature of the hand and the general condition of the patient, that it is sometimes impossible to say, if the obvious increase in sensibility is due to recovery of the nerve or only to more favourable general conditions.

The date at which sensation to prick is completely restored can be determined more satisfactorily. The analgesia retreats to the terminal phalanx of the little finger, and

TABLE III.—DIVISION OF

Case	Date of Injury	Nature of Injury	Operation and Result
No. 25, A. H. ..	Dec. 24, 1902	Cut wrist with soda-water syphon. All structures divided down to the bone (J. S.)	Primary suture, Dec. 24, 1902. Suppurated
No. 26, M. L. ..	Oct. 26, 1902	Cut wrist with jug. All structures divided down to the bone	Primary suture, Oct. 27, 1902. Suppurated
No. 27, A. W. ..	Mar. 10, 1901	Glass cut of wrist. Both nerves divided	Primary suture at another hospital. Suppurated
No. 28, G. B. .. [*Vide* Appendix, p. 321]	Sept. 24, 1902	Glass cut of wrist. Tendons were sutured, but not nerves	Secondary suture, April 17, 1903 (205 days). Both nerves found divided. First intention

it is easy to discover if this part is sensitive or not. The average period necessary for complete recovery of sensation to prick was 133 days, but the individual variation is great, extending in our cases from 84 days[1] to 192 days.

Division of the ulnar nerve below its dorsal branch causes loss of sensation to light touch over a considerable area of the palm. In two instances of primary suture of the nerve, this form of sensibility began to return in 234 and 133 days (an average of 183 days). The whole affected hand had become sensitive to light touch 424 and 217 days after suture.

MEDIAN AND ULNAR NERVES.

Return of Sensation			Muscles
Protopathic	Epicritic	Final Result	
Had begun Mar. 8, 1903 (74 days). Complete May 13, 1903 (140 days)	Began July 12, 1903 (200 days). Complete Sept. 23, 1903 (273 days)	Changed sensation had not entirely disappeared July 8, 1905 (726 days). Compasses perfect at 2 cm.	Sept. 23, 1903 (273 days), interossei and abductor pollicis acted voluntarily and 1st dorsal interosseous and abductor minimi digiti reacted to the interrupted current.
Began Mar. 5, 1903 (128 days). Complete Aug. 19, 1903 (295 days)	Began Aug. 19, 1903 (295 days). Complete Dec. 2, 1903 (399 days)	Line of change disappeared Feb. 17, 1904 (475 days). Aug. 23, 1905, compasses still bad at 2 cm.	Sept. 2, 1903 (308 days), opponens and abductor pollicis reacted to strong interrupted current. Feb. 17, 1904 (475 days), first dorsal interosseous reacted to interrupted current. July 13, 1904 (621 days), all muscles reacted to interrupted current. Oct. 20, 1903 (356 days), opponens and abductor acted voluntarily.
Nov. 10, 1901 (245 days), when first seen by us. Protopathic sensibility had returned	Began Jan. 24, 1902 (320 days). Complete Mar. 8, 1903 (728 days)	Line of change gone May 24, 1903 (804 days). With compasses at 3 cm. everything called "two," Aug. 21, 1905	Nov. 5, 1902 (605 days), opponens and adductor pollicis acting voluntarily; did not react to induced current. Mar. 8, 1903 (728 days), all muscles acted voluntarily and reacted to induced current.
Began Sept. 27, 1903 (163 days). Complete Dec. 20, 1903 (247 days).	Began April 10, 1904 (358 days).		

[1] In a boy of 10 years of age.

(*C*) *Median and Ulnar.*

In spite of the severity of the lesion and the great extent of the analgesia it produces, sensibility to prick began to be restored to the affected palm in two instances 74 and 128 days after primary suture, and the whole hand became sensitive to prick in 140 and 295 days. One patient (No. 27) was seen by us for the first time 245 days after primary suture, and by this time all analgesia had disappeared.

Thus, although the material at our disposal is small, it is evident that the length of time necessary for the restoration of sensibility to prick after division of both nerves does not materially exceed that required after division of the ulnar only. This result is particularly noteworthy, as in all the patients with division of both nerves, from whom these numbers were drawn, the wound suppurated.

As far as the return of sensibility to prick is concerned, it seems to matter little whether one or both nerves have been divided. But simultaneous division of the two nerves materially delays the return of sensation to light touch. On an average, in three instances, this form of sensibility did not begin to return until 271 days, and was not universally restored to the affected parts until 470 days, after suture. However, it must be remembered that in all these patients, the wound suppurated. But in spite of this objection, we are inclined to believe that simultaneous division of both nerves materially retards the return of sensibility to light touch.

(*D*) *Summary.*

Our records are sadly incomplete, and it is not possible to determine, with the accuracy we could wish, the period requisite for the various stages of recovery. But it will be well, as far as possible, to summarise our results with the warning that, since satisfactory cases are so few, the interjection of some unrecognised circumstance, even in a single instance, may have materially upset any of the following averages :—

	Protopathic		Epicritic	
	Began	Complete	Began	Complete
Ulnar with dorsal branch intact	?	133	183	320
Complete ulnar nerve	109	171	169	278
Median nerve	65	190	262	387
Median and ulnar nerves ..	101	217	271	470

From this table it will be seen that the earliest recovery of sensibility to prick occurs after primary suture of the median nerve. For reasons given above, we have purposely neglected the date at which the restoration of sensation began in those cases where the ulnar nerve was divided but the dorsal branch remained intact. It is after such an injury that the analgesia disappears completely with the greatest rapidity. Even when both nerves had been divided, sensibility to prick was restored in 217 days, or a little over six months.

The length of time necessary for complete recovery of sensibility to cotton-wool and to the intermediate degrees of temperature varied somewhat, but occupied about a year in most cases. Any defect in healing, particularly if it leads to the formation of pus, or of fibrous tissue around the nerve, materially hinders the return of the higher forms of sensation.

Chapter 3.—Recovery of Sensation after Incomplete Division of the Nerves of the Hand.

If a nerve has been bruised, or incompletely divided, it may become entirely incapable of conducting impulses, and the loss of sensation at first may resemble that which follows complete division. But, when the continuity of the nerve has not been destroyed, recovery may take place, not

TABLE IV.—MEDIAN

Incomplete Division of the Median Nerve.

Case	Date of Injury	Nature of Injury	Operation and Result
No. 29, C. B. .. [*Vide* Appendix, p. 302.]	Sept. 20, 1902	Cut wrist with glass bottle. Median nerve found swollen and redder than normal; on ulnar side it had been cut into. Tendon of flexor sublimis to index had been divided (J. S.)	Wound explored Sept. 20. Nerve left untouched. Tendon sutured. First intention
No. 30, D. B. ..	July 31, 1904	Glass cut of wrist. Median nerve incompletely divided. Four tendons of flexor sublimis divided	Tendons and nerve sutured Aug. 1, 1904. Healed by healthy granulation
No. 31, H. B. ..	Dec. 18, 1904	Glass cut of wrist. Median nerve incompletely divided	On Dec. 18, 1904, wound stitched without an anæsthetic. On June 15, 1905, explored and nerve examined (J. S.)
No. 32, A. S. ..	April 22, 1905	Glass cut of wrist. Median nerve cut into on ulnar side. Some tendons of flexor sublimis divided	Wound in nerve sutured and tendons reunited, April 22, 1905. First intention

Injury to Median Nerve.

Case	Date of Injury	Nature of Injury	Result of Injury
No. 33, H. E. T.	Dec. 26, 1903	Fractured forearm. Splint pressure. Volkmann's contracture	Complete loss of function in median nerve

Return of Sensation			Muscles
Protopathic	Epicritic	Final Result	
Began Oct. 22, 1902 (32 days). Complete July 12, 1903 (294 days)	Began Oct. 22, 1902 (32 days). Nearly complete July 12, 1903 (294 days)	Patient could not be found after July 12, 1903	Did not cease to act voluntarily. Did not react to interrupted current between Oct. 22, 1902, and Feb. 11, 1903 (143 days). To galvanism reactions were practically normal throughout.
Began Sept. 7, 1904 (37 days). Complete Dec. 14, 1904 (135 days)	Began Sept. 7, 1904 (37 days). Complete Dec. 14, 1904 (135 days)	Line of change well marked Aug. 16, 1905. Compasses good at 1·5 cm. (380 days)	Sept. 7, 1904 (37 days), abductor and opponens acted voluntarily, but did not react to the interrupted current until Oct 26, 1904 (85 days). To galvanism reactions were practically normal throughout.
Began Mar. 1, 1905 (73 days). Almost completely returned, Aug. 16, 1905 (168 days)	Began Mar. 22, 1905 (94 days). Almost completely returned Aug. 16, 1905 (168 days)	.. ..	Mar. 1, 1905, muscles acted voluntarily and reacted to interrupted current (73 days).
Began May 31, 1905 (38 days). Complete Aug. 30, 1905 (129 days)	Began Aug. 30, 1905 (129 days)	.. ..	May 31, 1905 (38 days), reacted to interrupted currents. July 14, 1905 (82 days), acted voluntarily.

Protopathic	Epicritic	Final Result	Muscles
Began July 3, 1904 (188 days). Complete Feb. 26, 1905 (425 days)	Began July 3, 1904 (188 days). Complete May 6, 1905 (493 days)	Compasses perfect at 1·5 cm. Aug. 27, 1905 (606 days).	July 24, 1904 (208 days), muscles reacted to interrupted current.

only more rapidly, but also in an entirely different manner from that observed after complete division. At the end of a period varying with the severity of the injury, sensation to prick begins to return. Approximately at the same time, light touch also begins to be appreciated over those parts of the area previously insensitive to this stimulus, which lie nearest to the wrist.

Thus, if a nerve is injured, but not divided, both sensibility to prick and to light touch begin to return together, in contradistinction to the order in which sensation is restored when the continuity of the nerve has been completely destroyed.

As recovery progresses, the two forms of sensibility continue to advance *pari passu*. For instance, if the median nerve has been injured, the gradual diminution of the analgesia on the fingers is accompanied by an equivalent increase in the sensibility of the palm of the hand to light touch.

With the power to appreciate light touch, the affected parts become sensitive to intermediate degrees of temperature. In fact, restoration of this form of sensibility over the proximal parts of the palm, at a time when the analgesia has scarcely begun to diminish in extent, is one of the earliest indications that the nerve has not been completely divided.

With the return of sensation to light touch and to the intermediate degrees of temperature, comes a coincident improvement in the answers given by the patient to the compass test. The power of discriminating two points is not only restored more rapidly, but more often returns completely than when the continuity of the nerve has been destroyed.

With regard to the principle underlying the manner in which sensation is restored, it matters little whether the nerve has been bruised or incised. We have, therefore, gathered together all the instances of injury and incomplete division on the same table.

But these partial injuries may produce very varying results. Sometimes every function of the nerve is destroyed for a time; sensation is lost and the muscles are paralysed,

exactly as if the nerve had been divided. This occurs most frequently when the injury is an incised wound; but it can also occur from the pressure of splints and bandages, or, even as in the following instance, from a blow over the ulnar nerve at the elbow.

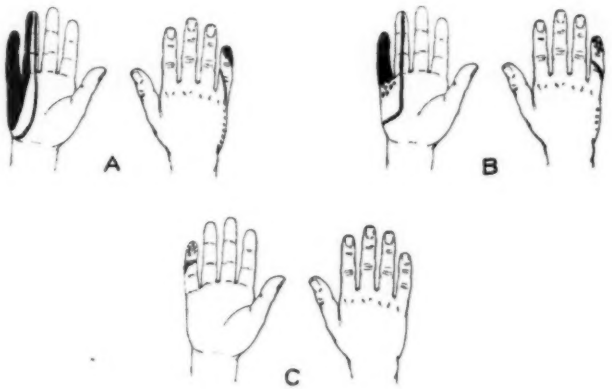


FIG. 6.

To show the loss of sensation produced in Case 36 by a blow over the ulnar nerve at the elbow. The area insensitive to cotton-wool and to the intermediate degrees of heat and cold is surrounded by a single line. The area of total cutaneous insensibility is marked in black. A shows the condition on February 29, B on March 2, C on March 9.

Case 36.—*Injury to the ulnar nerve at the elbow to illustrate the simultaneous return of the two forms of cutaneous sensibility.*

C. T. S., aged 27, was kicked on the inner side of the elbow whilst playing football on February 27, 1904. The ulnar half of the hand became numb and painful, but he was able to continue the game. When seen by one of us on the 29th, the trunk of the ulnar nerve was exquisitely tender, and he had lost sensation to cotton-wool over the area in fig. 6. Sensation to prick was lost over a considerable part of the ulnar palm, and over the palmar aspect of the little and part of the ring fingers. Over the same parts, he was completely insensitive to water at 55° C., and to ice. That part of the back of the hand supplied by the dorsal branch of the nerve was not affected. On March 2, four

days after the accident, we were able to examine him in greater detail. The appearance of the hand was unaltered, but sensation was profoundly affected. Prick, water at 55° C., and ice, were not appreciated over the palmar surface of the little finger. Two-thirds of the ring finger and part of the ulnar palm were insensitive to cotton-wool and the intermediate degrees of temperature.

TABLE V.—ULNAR

INCOMPLETE DIVISION OF THE ULNAR NERVE.

Case	Date of Injury	Nature of Injury	Operation and Result
No. 34, C. T. .. [*vide* Appendix, p. 312.]	Mar. 4, 1903	Glass cut of wrist. Flexor carpi ulnaris, and ulnar artery divided. Ulnar nerve almost completely divided *below dorsal branch*	Mar. 4, 1903. First intention
No. 35, F. H. ..	Jan. 21, 1904	Wrist cut with knife. Trunk of ulnar nerve cut into on ulnar aspect *above origin of dorsal branch*. No tendons divided (J. S.)	Jan. 28, 1904, injured nerve sutured with cat-gut. First intention

INJURY TO ULNAR NERVE.

Case	Date of Injury	Nature of Injury	Result of Injury
No. 36, C. T. S.	Feb. 27, 1904	Kick over internal condyle of humerus ..	Loss of both forms of sensation over distribution of ulnar, excepting its dorsal branch
No. 37, E. H. ..	May, 1904 ..	Struck inner side of elbow on a stone step	Loss of epicritic sensibility over full ulnar area
No. 38, T. F. ..	Sept. 10, 1904	Separated lower epiphysis of humerus. Bad union. Oct. 28 set afresh. Forearm bandaged in full flexion	Loss of epicritic sensibility over full ulnar area

He could perform all the movements of the hand, but abduction of the little finger was weak, and it tended to assume the position usually seen in ulnar paralysis. The interossei also

NERVE.

Return of Sensation			Muscles
Protopathic	Epicritic	Final Result	
Almost returned June 17, 1903 (104 days). Completely returned Aug. 26, 1903 (174 days)	Began June 17, 1903 (104 days). Complete Aug. 26, 1903 (174 days)	Sensation to light touch again became lost with the cold weather and did not clear finally until Feb. 26, 1904 (358 days). Line of change still present May 6, 1905 (793 days)	Acted voluntarily, June 17, 1903 (104 days). All reacted to interrupted current, Aug. 26, 1903 (174 days).
No loss..	Light touch only lost. 40° C. and 22° C. appreciated from date of injury. Complete return Mar. 16, 1904 (56 days)	No line of change. All forms (including compasses) perfect, April 20, 1904 (90 days)	Acted voluntarily, Sept. 14, 1904 (236 days). Reacted to interrupted current, Nov. 2, 1904 (284 days). Reacted briskly to galvanism from beginning.

Protopathic	Epicritic	Final Result	Muscles
Began Mar. 2, 1904 (3 days). Complete Mar. 12, 1904 (13 days)	Began March 2, 1904 (3 days). Complete March 12, 1904 (13 days)	Perfect March 12, 1904 ..	No movement absolutely lost, but abduction of little finger was poorly performed. Reaction to interrupted current never lost. Increased irritability to galvanism.
No loss..	Began Aug. 24, 1904. Complete Sept. 28, 1904	Perfect Nov. 23, 1904 (about 181 days)	No paralysis. Wasting of all interossei. Reaction to interrupted current normal.
No loss..	Had returned by Jan. 4, 1905 (67 days)	Line of change present July 14, 1905 (257 days). Compasses perfect at 1·5 cm.	No paralysis.

acted feebly. All the muscles reacted to the interrupted current; to galvanism they had become over-sensitive, reacting briskly with a current of 3 ma., and A.C.C. was considerably in excess of

K.C.C. This increase of susceptibility was best marked in the abductor muscles of the little and index fingers. Compared with the reaction of similar muscles of the sound hand, the increase was obvious and the polar reversal striking.

Sensation continued to return with rapidity; the area of loss to prick and that of loss to light touch retreated step by step. On March 9, the only loss of sensation that could be discovered occupied the skin over the palmar surface of the terminal phalanx of the little finger. One week later, this had completely disappeared.

TABLE VI.—INJURY TO

Case	Date of Injury	Nature of Injury	Result of Injury
No. 39, W. E. ..	April 30, 1904	Compound fracture of humerus. Median nerve exposed in wound. Splint pressure on forearm. Splints removed during third week in June, 1904	Complete loss of function in median and ulnar nerves
No. 40, A. S. ..	April 10, 1903	Fracture of radius. Splint pressure. Sore appeared on fourth day. Arm in splints six weeks	Volkmann's contracture. Complete loss of function of ulnar nerve in the hand; incomplete median
No. 41, E. P. ..	July 26, 1902	Injury to arm. Splints fourteen days. Blisters seen seven days after injury	Complete loss of function in median and ulnar, excepting its dorsal branch

Sometimes the injury is not sufficiently severe to produce complete analgesia of any part of the area supplied by the nerve affected. But sensibility to light touch and to the minor degrees of temperature may be abolished over the full extent of the injured nerve. More commonly, stimulation with cotton cannot be appreciated, and the compasses show profound lowering of sensibility, although intermediate degrees of temperature can still be appreciated over the area

of the injured nerve. Under such circumstances, sensation will be restored with remarkable rapidity.

Case 35.—*Incised wound of the ulnar nerve producing partial loss of sensation.*

On January 21, 1904, F. H., aged 15, cut his left forearm with a pocket knife. It bled little, and he did not visit a medical man until three days later. When first seen by us on January 28 there was an oblique wound about half an inch in

MEDIAN AND ULNAR NERVES.

Return of Sensation			Muscles
Protopathic	Epicritic	Final Result	
Already begun Nov. 2, 1904 (185 days). Complete Dec. 21, 1904 (233 days)	Began Dec. 7, 1904 (219 days). Complete April 5, 1905 (337 days)	Compasses perfect at 1 cm. April 5, 1905 (337 days)	Feb. 1, 1905 (274 days), first dorsal interosseous and abductor minimi digiti acted voluntarily. April 5, 1905 (337 days), all muscles acted and reacted to interrupted current.
Returned completely Sept. 30, 1903 (172 days)	Returned completely Jan. 6, 1904 (269 days)	Feb. 8, 1905 (301 days), sensation perfect. No line of change	Paralysis of all intrinsic muscles of hand. No reaction to interrupted current. Brisk reaction to galvanism. July 6, 1904 (453 days), all muscles reacted to interrupted current.
Sensation had not begun to return Sept. 17, 1902 (37 days). Returned completely Nov. 14, 1902 (94 days)	Sensation had not begun to return Sept. 17, 1902 (37 days). Had almost completely returned Nov. 14, 1902 (94 days)	Compasses at 1 cm. perfect Feb. 18, 1903 (189 days)	Paralysis of all intrinsic muscles of hand. No reaction to interrupted current. Feb. 18, 1903 (189 days), all muscles acted well and reacted to interrupted current.

length, which was healing by granulation. It was situated one and a half inches above the head of the ulna at the extreme border of the forearm. The hand was held with the fingers over-extended at the metacarpo-phalangeal joints and flexed at the interphalangeal, these changes being most marked in the little and ring fingers. The little finger was abducted and the hand had assumed the typical position seen after division of the ulnar nerve. True adduction of the thumb was impossible, and none of the interossei were acting.

Sensation to cotton-wool was lost over the area in fig. 7, but minor degrees of temperature could be appreciated. Sensation to prick was unaffected.

The wound was explored the same day and the ulnar nerve exposed. It was injured just above where the dorsal branch was given off, being severed for about two-thirds of its breadth. On February 10, light touches were perceived everywhere, but were less distinct over the area affected than elsewhere, and by April 20 no difference could be found between the sensibility of the two hands.

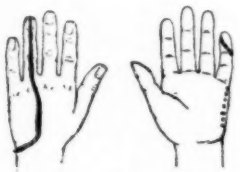


FIG. 7.

From Case 35, to show the area rendered insensitive to light touch by an incised wound of the ulnar nerve.

In conclusion, we have found that injury to a peripheral nerve may produce all the results, both sensory and motor, which follow its complete division. But the two forms of sensation may begin to return approximately at the same time, and be restored *pari passu*. This method of restoration of function differs fundamentally from that observed when the nerve has been reunited after complete division.

Injury to a nerve not sufficiently severe to produce analgesia may cause complete loss of sensibility to light touch, and to intermediate degrees of heat and cold. Or sensation to cotton-wool only may be lost, while all forms of temperature can be appreciated over the affected area.

CHAPTER 4.—NERVE SUPPLY OF THE FOREARM.

Without the knowledge gained from lesions of the median and ulnar nerves, it would be impossible to unravel the complexities of the sensory nerve supply to the forearm. An attempt will be made in this chapter as far as possible

to analyse the part played by each of the main nerve trunks. Nowhere is their distribution, as revealed by anatomy, less in accord with their functional supply than on the forearm; for the considerable anastomoses of both larger and smaller branches make it impossible to delimit by dissection their ultimate distribution. Moreover, anatomy can demonstrate only, that the branches of one or more nerve trunks run to certain parts, without determining the form of sensibility they mainly subserve. A part supplied by fibres from two main nerves is, to the anatomist, an area of overlapping sensibility. But, from the physiological aspect, the problem of nerve supply is less simple. On the palm of the hand, as far as the higher forms of sensation are concerned, the overlapping of the median and ulnar nerves is trivial; but we have shown that the mechanism by which the palm is rendered sensitive to prick and to the more extreme forms of temperature overlaps, to a degree scarcely suspected by most anatomists.

But there are other difficulties in determining the ultimate destination of a nerve, besides the wide diversity in distribution of these two forms of sensibility. Division of a nerve produces loss of sensation over those parts to which that nerve alone is distributed. Only by stimulation of the trunk of a nerve, or by widespread destruction of surrounding nerves, can the full extent of the parts it supplies become manifest. Now, true hyperalgesia, which gives the full distribution of the sensibility to pain conducted by any nerve trunk, is so rare that it can seldom be utilised for this determination; excessive sensibility to the higher forms of sensation does not exist as a consequence of injury to peripheral nerves.

Almost in every case, we shall first determine the extent of the loss of sensation produced by dividing each of the nerves of the forearm. By this means we can discover how much of the forearm is supplied exclusively from any particular nerve. This will be spoken of as its "exclusive" supply.

But, in order to determine the full distribution of any single nerve, it becomes necessary to seek for cases where that nerve has remained uninjured, although the branches

supplying adjacent areas have been completely divided. Any sensibility that remains must then be due to the uninjured nerve. This will be called the method of "residual sensibility."

In a few instances, we have seen true hyperalgesia produced by irritation of the trunk of a nerve. From them we have been able to determine directly the full extent of the area supplied from that particular branch with sensibility to prick.

§ 1.—*The Post-axial Half of the Forearm.*

The internal cutaneous (n. cutaneus antibrachii medialis) takes its origin from the inner cord of the brachial plexus in close association with the ulnar nerve. Excepting for anastomoses with the lesser internal cutaneous above, and with the ulnar over the front and back of the hand, this nerve supplies an isolated area on the post-axial half of the forearm. In the following case, excision of nearly three inches of the internal cutaneous nerve high in the arm discovered to us in full the extent and nature of its exclusive supply.

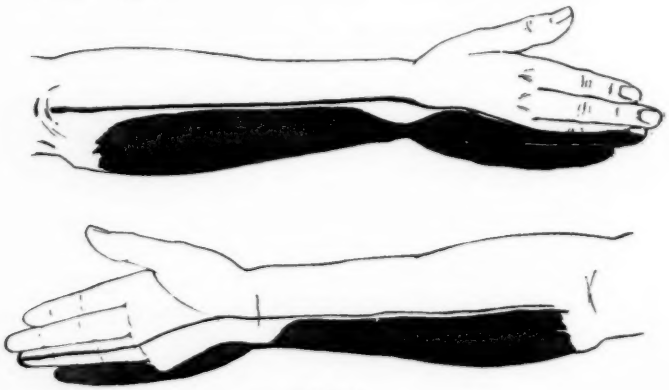


FIG. 8.

To show the loss of sensation produced in Case 42 by excision of a portion of the ulnar and internal cutaneous nerves in the lower third of the arm. The area insensitive to light touch and to intermediate degrees of heat and cold is enclosed in a single line. Total cutaneous insensibility is shown in black. Above the elbow the loss could not be determined with certainty in consequence of the position of the wound.

Case 42.—*Excision of a portion of the internal cutaneous after previous resection of the ulnar.*

Edgar T., aged 57, came under the care of Mr. Jonathan Hutchinson, jun., at the London Hospital, suffering from loss of power and disturbance of sensibility in the hand. On the inner side of the arm, in its lower third, a hard tumour could be felt, apparently in connection with the ulnar nerve.

The hand was held in the position characteristic of ulnar paralysis; the two terminal joints of the little finger were flexed, the metacarpo-phalangeal joint over-extended. The interosseous spaces were wasted and all the muscles of the hand supplied by the ulnar nerve were paralysed. Sensation to light touch, to water at 20° C. and at 40° C., were lost over the full ulnar area on the palm and dorsal surface of the hand. On the dorsal surface, the loss to prick, to heat and to cold, corresponded in extent with that to light touch; on the palm, the little finger, and a narrow strip on the extreme ulnar border were alone insensitive to all cutaneous stimuli.

On October 26, 1904, Mr. Hutchinson cut down upon the swelling in the arm. The ulnar nerve was traced into it from above, and the internal cutaneous lay across its surface. He, therefore, removed the whole tumour together with about three inches of both nerves. After the operation, the loss of sensation had extended greatly. The skin of the post-axial half of the forearm was insensitive both in front and behind up to a line running through the centre of the wrist. Both these borders were continuous, on the front and back of the hand, with the limits of loss to light touch that existed before the operation. In fact, the border of the final anæsthesia closely corresponded on the flexor surface to a line drawn from the tendon of the biceps to the axis of the ring finger, and from the olecranon to the axis of the same finger on the back of the forearm. The borders of loss to prick and all degrees of heat and cold in the forearm coincided exactly with these limits, but fell away both in front and behind in the neighbourhood of the wrist (*vide* fig. 8).

In order to obtain so extensive an area as that we have just described, it is necessary that the nerve shall be completely divided above the lower third of the arm. Anywhere below the elbow, an injury usually destroys one only of its two branches, producing loss of sensation to light touch and minor degrees of temperature over either the front or the back of the post-axial surface of the forearm,

but no absolute loss of sensibility to prick, heat and cold. If the anterior branch is divided, the loss will be limited by a sharp border on the flexor surface, but will gradually merge into the normal parts over the back of the forearm by a band of diminished sensibility. Division of the posterior branch will cause an area of anæsthesia on the back of the forearm strictly limited towards the radial side, but fading gradually on the ulnar border into parts of normal sensibility. Thus, the internal cutaneous nerve supplies the skin of the post-axial half of the forearm with both forms of sensibility. Its two branches overlap considerably. One supplies the whole of this post-axial area on the front (flexor aspect) of the forearm, the other its dorsal (extensor) aspect. The indeterminate borders of these two areas of anæsthesia, where they come into contact, show that the two branches overlap even for the conduction of sensation of light touch. For sensation of pain the overlapping must be extreme, since little or no analgesia is produced by dividing one branch only.

It is rarely possible to mark out the full supply of any nerve in the forearm by means of the hyperalgesia produced by irritation of its trunk. But in Case 84,[1] where a bullet passed through the forearm from the radial to the ulnar aspect, the whole extent of the area supplied with sensibility to pain from the internal cutaneous was intensely tender. A comparison of fig. 37 on p. 320 with that of the area obtained when the internal cutaneous was divided (fig. 8) shows the different results produced by the two methods.

§ 2.—*Sensation on the Pre-axial Side of the Forearm.*

The sensory innervation of the post-axial half of the forearm and hand is comparatively simple; it is carried out almost entirely through the internal cutaneous and ulnar nerves. The conditions on the pre-axial half are more complex. The musculo-cutaneous, the radial, and the median are all in some degree responsible for its innervation, and to these nerves on the back (extensor surface) of the forearm

[1] *Vide* Appendix, p. 319.

is added the lower external cutaneous branch of the musculo-spiral. The sensibility of the post-axial half of the forearm and hand depends on two nerves only, whilst at least four enter into the supply of the skin on the pre-axial half.

Not one of these nerve branches supplies in the forearm a self-contained area analogous to that of the internal cutaneous. Division of any one of them causes at most an area of loss of sensation to light touch, usually with ill-defined borders. Sensibility to prick is affected to an even less degree.

Radial.—(Ramus superficialis nervi radialis.) After the musculo-spiral (n. radialis) has given off its three cutaneous branches and has supplied the extensor muscles, it divides into the posterior interosseous (r. profundus n. radialis), and the radial (r. superficialis n. radialis) nerves. In all works on anatomy, a certain portion of the skin over the dorsal surface of the thumb and over the back of the hand is assigned to the latter branch. But the anastomoses between the various nerves supplying the pre-axial border of the forearm and hand are so free that it is impossible to determine by dissection their ultimate distribution; the area assigned to any one nerve in the books on anatomy, when not fanciful, is nothing but the measure of the skill of generations of dissectors. An area of tenderness due to irritation of the trunk of the nerve can reveal the full extent of its distribution; its division will show only how far its exclusive supply extends.

Nowhere is this more apparent than in the description given of the supply of the radial nerve; for it has long been known that division of the musculo-spiral in the neighbourhood of the spiral groove causes no definite loss of sensation over the thumb or back of the hand. The following case adds another to the long list scattered among the literature of the last half century (Case 43).[1]

Frank L. was admitted to Poplar Hospital on June 28, 1903, with a fracture of the lower end of the right humerus. Two days later, as all attempts to reduce the deformity had failed, operation was resorted to. After the operation, para-

[1] *Vide* Appendix, p. 323.

lysis of all the muscles supplied by the musculo-spiral nerve appeared, but nowhere was there any loss of sensation. On August 3, 1903, one of us cut down upon the site of the previous incision, and found the musculo-spiral nerve had been divided; the two parts were adherent to the bone, and surrounded by fibrous tissue which united the retracted ends. These were excised together with the intervening fibrous tissue, and the nerve was reunited with silk sutures. A portion of the supinator longus was sewn beneath the nerve to prevent it from again forming adhesions to the bone. All the muscles on the extensor aspect of the forearm, including the supinator longus, were paralysed, and did not react to the interrupted current, and yet at no time was there any demonstrable loss of sensation to light touch, to prick, to heat, or to cold.

Although division of the parent trunk produces no change in sensation, destruction of the radial nerve in the lower third of the forearm causes definite loss over the back of the thumb and outer part of the thenar eminence. But this loss is confined to the higher forms of sensation. Stimulation with cotton-wool or with a temperature of 40° C. is not appreciated; a prick, ice, or water at 50° C., evoke an immediate response.

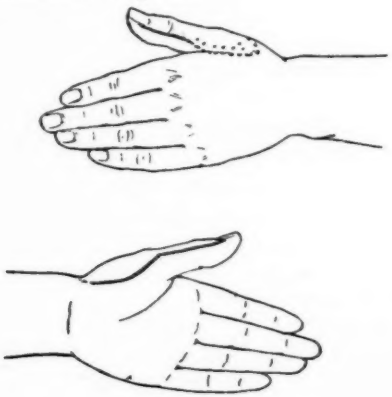


FIG. 9.

To show the area that became insensitive to light touch and minor degrees of heat and cold in Case 44, after division of the radial nerve (r. superficialis n. radialis). For a complete series of diagrams, and for a full account of this case, *vide* Appendix, p. 324.

In Lena LeB. (Case 44[1]) the radial nerve was divided for therapeutic reasons at the point where it passes under the tendon of the supinator longus. This abolished sensation to light touch, and to minor degrees of heat and cold over the back of the thumb and dorsal aspect of the first metacarpal bone. The boundary of this anæsthetic area (fig. 9) was firmly defined on its palmar aspect; there was no gradual transition from parts insensitive to light touch to those of normal sensibility. It followed a line of great theoretical interest running from the radial corner of the thumb-nail along the lateral aspect of the thumb to the metacarpophalangeal joint. From this point it swung inwards towards the thenar eminence, including a considerable portion of the skin that lay over the abductor and opponens pollicis. On the ulnar aspect of the thumb, this anæsthetic area was also bounded by a firm line; but, over the dorsal surface of the metacarpal, the loss of sensation merged gradually towards the back of the hand into parts of normal sensibility.

Until the radial nerve reaches the wrist, the fibres of which it is composed innervate exclusively no part of the hand. On the peripheral side of that point, it alone supplies the higher forms of sensibility to an area on the back of the thumb and to a small strip of skin on the outer side of the thenar eminence. No loss of sensation to pain, or to the more extreme degrees of temperature, can be produced by destruction of this nerve in any part of its course.

External cutaneous (n. cutaneus antibrachii lateralis seu cutaneus brachii externus).—We have seen no case where the whole external cutaneous alone was divided. But in the following instance, part of the distribution of this nerve was exquisitely marked out by tenderness, due to irritation of its anterior branch.

Case 45.—*Hyperalgesia over an area on the forearm produced by injury of the anterior division of the external cutaneous nerve.*

Leonard E. first came under our notice in February, 1905, with a history that, fourteen weeks before, he had slipped with a jug in his hand and cut the front of his forearm. The wound

[1] *Vide* Appendix, p. 324.

was sewn up at once, but two weeks later it was reopened because the patient had begun to suffer pain. This pain slowly increased, and for about three weeks before we saw him had troubled him greatly.

About two and a half inches (6·5 cm.) above the fold of the wrist, on the anterior (flexor) surface of the forearm, was an almost transverse scar, three-quarters of an inch (2 cm.) in length. On the radial side was a second smaller scar, three-eighths of an inch (1 cm.) in length, which looked as if it might have resulted from an incision. Extending from the region of these scars in the direction of the hand, a considerable area was profoundly tender to a point dragged lightly across the skin, and to pressure with any blunt object, such as the head of a pin. To light touch, to prick, to heat, and to cold, sensation was perfect, and with the compasses an equivalent record was obtained on both the sound and affected limbs.

As the patch of hyperalgesia was obviously due to some injury to the anterior branch of the external cutaneous, the nerve was explored by one of us. It was found to be adherent to the scar and implicated in fibrous tissue. A small portion was excised and the two ends sutured together. All pain ceased immediately. But the operation was followed by no diminution in any form of sensation over any part of the area supplied by the divided nerve.

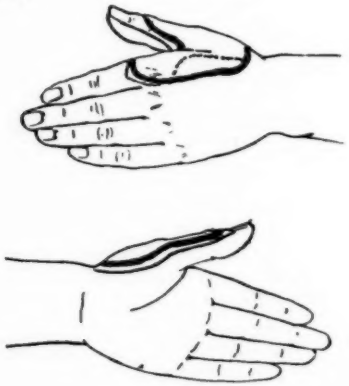


FIG. 10.

The area which became insensitive to light touch and minor degrees of heat and cold after division of the posterior branch of the external cutaneous is enclosed by a thin line, that insensitive to prick and to all degrees of temperature by a thick black line. The radial (r. superficialis n. radialis) had been previously divided, and the result is shown on fig. 9. For a full account of this case *vide* Appendix, p. 324.

But, if the radial be divided in addition even to one branch of the external cutaneous, the loss of sensation becomes considerable. We have no instance where the anterior branch was affected together with the radial, but Case 44 showed the effect produced by dividing the posterior division of the external cutaneous after destruction of the radial. At the time when we undertook to make the painful spot on her thumb insensitive, our knowledge of the distribution of these nerves to the radial half of the back of the hand was less complete than at present. Anxious to cause as little injury as possible, we proceeded to denervate the part by degrees, and thus at one period we had the opportunity of examining, in an uncomplicated form, the loss of sensation produced by destruction of the radial and posterior division of the external cutaneous. The anæsthesia that followed division of the radial nerve has already been described, and appears on fig. 9. Subsequent destruction of the posterior division of the external cutaneous produced an extension of this loss of light touch, which now occupied the back of the hand over the first interosseous space and region of the knuckle of the index finger (fig. 10).

Division of the radial nerve alone had produced no loss of sensibility to prick, but subsequent destruction of the posterior branch of the external cutaneous caused a loss of sensation to prick, even more extensive than the loss to cotton-wool. Over a patch on the back of the hand, stimulation with cotton-wool was appreciated, but all sensibility to prick was lost.

If, in addition to the radial, both branches of the external cutaneous are divided, the loss of sensation both to light touch and to prick occupies almost the whole of the pre-axial border of the forearm and back of the hand.

This was well seen in the case of one of us (No. 46) after the radial (r. superficialis n. radialis) and external cutaneous had been divided, for experimental purposes, in the neighbourhood of the bend of the elbow. A full account of this experiment will form the subject of a subsequent paper, but fig. 11 will be sufficient to show the extent of the anæsthesia and analgesia produced by dividing these two nerves. The

anterior border on the flexor surface of the forearm corresponded exactly with the axis of the limb to all forms of cutaneous stimulation. On the extensor aspect the loss of sensation was less definite; the loss of sensation to prick and that to light touch did not exactly coincide, and both were bounded by a sinuous border. On the back of the hand, both forms of loss of sensation were co-terminous except over the outer side of the thenar eminence and both lateral aspects of the thumb.

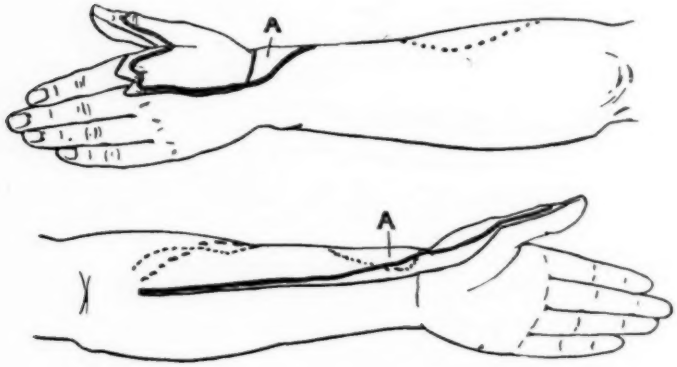


FIG. 11.

To show the loss of cutaneous sensibility produced by dividing the radial (ramus superficialis n. radialis) and external cutaneous nerves in the neighbourhood of the elbow. The thick line bounds the area insensitive to prick. The thinner line encloses the parts insensitive to cotton-wool. Both the thick and the thin line are dotted wherever the borders of the area of loss of sensibility were not sharply defined.

The triangle marked **A** was insensitive to prick but sensitive to stimulation with cotton-wool.

An exactly similar loss over the lower third of the forearm and over the back of the hand was produced by a circular wound around the radial half of the forearm (Case 47, *vide* Appendix, p. 327). Both these instances prove, that the back of the hand and the greater part of the back of the thumb is supplied exclusively by the radial and external cutaneous.

The flexor aspect of the pre-axial half of the forearm is innervated entirely by the external cutaneous, and destruction of both branches of this nerve brings out a line corresponding to the axis of the limb. But the extensor aspect receives its supply also from the lower external cutaneous branch of the musculo-spiral, and the full extent of skin innervated by this nerve is beautifully shown on fig. 11. For here every nerve to the pre-axial half of the forearm, with the exception of this branch of the musculo-spiral, had been divided; any

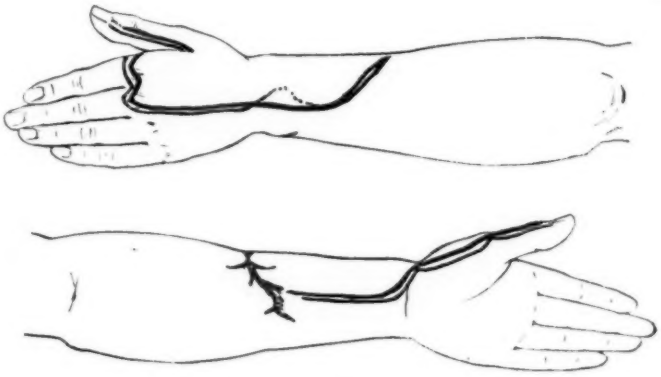


FIG. 12.

From Case 47 to show the area of loss of sensation produced by the accidental division of the radial (r. superficialis n. radialis) and external cutaneous nerves. The jagged scar is represented running across the flexor surface of the forearm. The area insensitive to light touch is enclosed by a thin line, that insensitive to all cutaneous stimulation by a heavy black line (*vide* Appendix, p. 327).

sensation that still remained must have travelled by means of this nerve. We know, therefore, that it supplies sensation as low as the wrist, and that the area of its supply merges with, and overlaps, that of the external cutaneous and radial It is a remarkable fact, that, in both Case 46 and Case 47, the cutaneous branch of the musculo-spiral seemed to be incapable of endowing as large an area on the back of the wrist with sensibility to prick as with sensibility to light touch; in consequence, a small area was present, especially

well marked on fig. 11, where the patient was sensitive to light touch, but insensitive to prick and the extremes of heat and cold.

Before passing away from the pre-axial border of the forearm, it will be well to consider the distribution of the median nerve in the light of the knowledge we have gained of the radial and external cutaneous. For, by division of these two nerves, all collateral supply to the back of the middle and index fingers and to the outer part of the thenar eminence is entirely cut off.

The border of the loss of light touch runs for a short distance down the axis of the middle finger (fig. 11 and fig. 12); at a point about half-way down the basal phalanx it turns sharply towards the radial side, to drop into the cleft between the middle and index fingers. Thence it rises again, to enclose about one-half of the skin over the dorsal surface of the basal phalanx of the index finger. It then passes across the first dorsal interosseous space, close to the free edge, to reach the lateral aspect of the thumb near the base of the first phalanx. On the ulnar aspect of the thumb, the border of the anæsthetic area runs almost in a straight line to the edge of the thumb-nail. On the radial aspect of the thumb and outer aspect of the thenar eminence, the boundary of loss of light touch corresponds exactly to that seen when the radial is divided low in the forearm (*vide* fig. 9).

The loss of sensation to prick is at every point slightly less than the loss to light touch. Moreover, in Case 46, and Case 47, the terminal phalanx of the thumb around the root of the nail was not completely analgesic. But, if the median is also divided, the whole of the thumb becomes entirely insensitive to prick. In Case 44, division of the branch of the median running to the ulnar aspect of the thumb caused complete analgesia of that half of the terminal phalanx which before had been partly sensitive to prick.

We are now in a position to determine, by the method of residual sensibility, the full extent of the area on the back of the hand, innervated by the median nerve. The series of cases we have cited, where the radial and external cuta-

neous were divided, shows that the median sends fibres to the following area. It supplies with sensibility to light touch the terminal two and a half phalanges of the index and middle fingers, the whole palmar aspect of the thumb, and all excepting the outer third of the thenar eminence. As far as sensation to light touch is concerned, this part of the thenar eminence is innervated from the radial, but its sensibility to pain comes through the median and external cutaneous nerves.

The median nerve supplies sensibility to prick, and the more extreme degrees of temperature to the terminal phalanges and at least three-quarters of the basal phalanx of the index and middle fingers. The proximal part of the thenar eminence receives its sensibility to these stimuli through both the median and external cutaneous nerves. This accounts for the infrequency with which the proximal part of the thenar eminence becomes analgesic in consequence of division of the median nerve.

Chapter 5.—Injuries to the Brachial Plexus.

The nerve trunks which compose the brachial plexus are not uncommonly injured by violence to the shoulder, particularly if the humerus is dislocated. But it is rare for such injuries to cause complete paralysis of sensation over the distribution of any one cord; sensibility to light touch is usually abolished over a well-defined area of considerable size, but a prick is everywhere appreciated, or the extent of the analgesia is comparatively trifling. The following case illustrates the usual results of such an injury.

Case 48.—*Injury to the inner cord of the brachial plexus.*

On January 1, 1903, an elderly man fell over a door-mat, dislocating his left shoulder. The next morning, he noticed he could not move his hand. On the third day following the accident, he came to the London Hospital, where the dislocation was reduced, and the arm strapped and bandaged across his chest. So it remained for fourteen days, and when the bandages were removed

he complained of weakness of the arm and hand. On February 25, when he first came under our care, his condition was as follows. The shoulder-joint was stiff, and movement was somewhat limited, especially when he attempted to raise his arm. There was no change in the appearance of the skin or nails. Light touch was not appreciated over the whole ulnar aspect of the forearm and hand on both its flexor and extensor aspects. Over this area, water at 22° C. and at 38° C. was nowhere appreciated as cool or warm; ice, and water at 50° C. were recognised everywhere correctly. Sensation to prick was unaffected, and no definite line of change could be marked out by drawing a pin across the skin from normal to abnormal parts.

The hand was held with the thumb abducted and extended; the fingers were extended at the metacarpo-phalangeal, and slightly flexed at the interphalangeal joints, and the little finger was also somewhat abducted. Thenar and hypothenar eminences were wasted, and the interosseous spaces deeply hollowed. The flexor carpi ulnaris was not acting, and, on telling him to close his fingers, the wrist was extended and the fingers feebly flexed at the interphalangeal joints. None of the intrinsic muscles of the hand, including those of the thumb, could be voluntarily contracted, but the long muscles of the thumb were acting well. The flexor carpi ulnaris and all the intrinsic muscles of the hand failed to react to the interrupted current, and contracted sluggishly to galvanism.

He rapidly recovered sensation, and by March 8, 1903, light touch, although materially diminished, was appreciated over the whole forearm and hand. Sensibility to minor degrees of heat and cold had also returned, and water at 22° C. and 38° C. was accurately distinguished.

In this case, the inner cord of the brachial plexus must have suffered in consequence of dislocation of the shoulder, the injury being only sufficient to abolish for a time sensibility to light touch and minor degrees of temperature.

Case 49.—*Profound loss of sensation produced by dislocation of the shoulder.*

In the case of Arthur M., a similar injury produced a more profound paralysis of sensation. On October 2, 1901, he dislocated his right humerus. He was admitted at once, and the dis-

location was reduced under an anæsthetic. The next day it was discovered that sensation was lost over the ulnar half of the forearm and hand, and that all the muscles in the hand supplied by the median and ulnar nerves were paralysed. When he came under our observation on December 4, 1901, the condition was

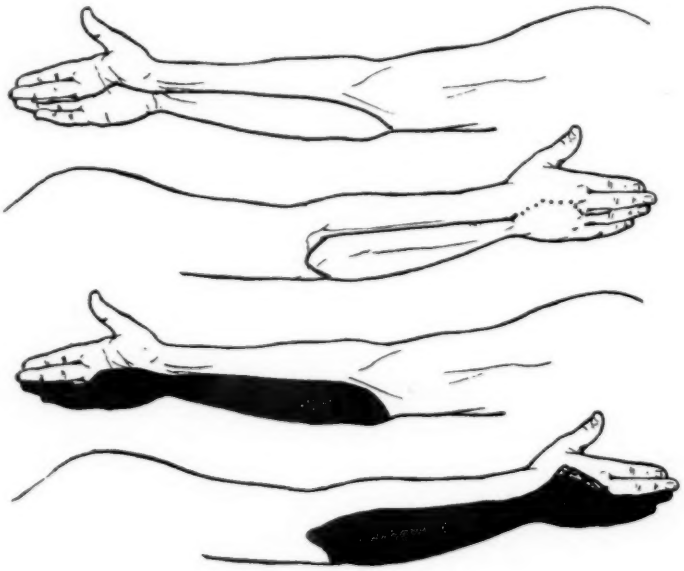


Fig. 13.

To show the area which became insensitive in Case 49 in consequence of dislocation of the shoulder. The upper two figures show the extent of the loss to light touch; the lower two the area insensitive to prick.

exactly that found on the morning after the dislocation had been reduced. Over the area shown in fig. 13 every form of cutaneous sensibility was lost. No movement of the thumb and little finger could be performed and all the interossei were paralysed. The flexor carpi ulnaris, the ulnar half of the flexor sublimis, and

the small muscles of the hand did not react to the interrupted current; but the extensor muscles and flexor carpi radialis responded normally.

Here the lesion must have been sufficiently severe completely to destroy conduction in the inner cord of the brachial plexus on the central side of the point where the inner head of the median is given off.

In the following case, the injury was still more severe, and for a time conduction must have been entirely interrupted in all the three cords of the brachial plexus.

Case 50.—*Fracture of the surgical neck of the humerus, causing rupture of cords of the brachial plexus.*

Alfred H., a boy of 14, was brought to the London Hospital on October 11, 1898, and admitted under the care of Mr. Jonathan Hutchinson. A large box had fallen upon him, striking his left shoulder; he was unconscious and collapsed. The humerus was fractured through its surgical neck, and signs pointed to grave internal injury, probably rupture of the kidney. He slowly recovered, and the bone united firmly. On December 12, 1898, he was first seen by one of us, in consequence of the remarkable paralysis both of motion and sensation in the left arm. He was an unusually intelligent boy, well developed for his age. All the muscles around the shoulder-joint, in the arm, forearm, and hand were greatly wasted. The left arm hung powerless to his side. All the muscles of the left hand and forearm, together with the brachialis anticus, biceps, triceps, deltoid, and latissimus dorsi, were paralysed. None of the movements, usually associated with contraction of the pectoralis major, could be performed. The rhomboids, serratus magnus and upper part of the trapezius contracted well; the lower part of the trapezius was almost certainly acting. All reaction to the interrupted current was abolished in the muscles of the hand and forearm, the biceps, deltoid, pectoralis major, supra- and infra-spinati, and the latissimus dorsi. The serratus magnus, trapezius and rhomboids reacted briskly. To galvanism all the muscles that had previously failed to react to the interrupted current contracted sluggishly, but the rhomboids, serratus, and both parts of the trapezius reacted with a brisk contraction.

FIG. 14.

To show the area which became insensitive to all forms of cutaneous stimuli in Case 50, in consequence of rupture of the cords of the brachial plexus.

All forms of cutaneous sensibility were lost over the area shown in fig. 14. Deep touch was not appreciated up to the elbow, but undoubtedly produced sensation over the whole of the arm above that joint.

The left hand was blue, cold and swollen; the nails showed no definite change. He had burnt the fingers at the fire, but the burns were healing well.

The left palpebral fissure was smaller, and the whole eye looked somewhat sunken compared with the right. In daylight the right pupil measured 4 mm., the left 3 mm., and when shaded the right enlarged to 6 mm., the left to 4 mm. The pupil on the affected side was somewhat oval in shape with its long axis placed vertically; it dilated well to a 2 per cent. solution of cocaine and became regular in outline. At the same time the narrowing of the palpebral fissure disappeared, so that excepting for the dilated pupil no difference could be detected between the two eyes.

On December 16, 1898, Mr. Hutchinson explored the brachial plexus above the clavicle and found that the upper and middle trunks were matted in firm fibrous tissue; the remaining parts he was unable to see. Both trunks were incised and found to consist at the point of the incision of tough fibrous tissue; a small portion was removed and the ends reunited.

This procedure made no alteration in the extent of the motor or sensory paralysis, showing that all the fibres entering these cords from the limb had been completely interrupted as a consequence of the accident.

By August, 1902, he had grown to be a man, but the injured arm showed an extraordinary combination of wasting and deficient growth. The fingers were flexed into the palm; the nails were long and curved, but not tender. No change could be detected in the elbow-joint, and movement was free, except for the limitation due to contracture of the biceps. The deltoid, triceps, supinator longus, and all the extensors were still paralysed. The pectoralis major, latissimus dorsi, trapezius, and serratus, acted well, and even the biceps, in spite of its contracted condition and small size, was acting. The wrist was flexed by means of the flexors of the fingers which were permanently shortened, so that their contraction produced no movement in the fingers. All the intrinsic muscles of the hand were entirely paralysed and profoundly wasted.

Sensation to light touch was lost over an area so exactly that of four years before that the two figures were identical. But

sensibility to prick and to the more extreme degrees of heat and cold had recovered to a remarkable degree. The whole hand, back and front, was still insensitive, and the analgesia extended for a short distance above the wrist, both in front and behind. Water at 38° C. was not appreciated over the large area of the upper limb insensitive to light touch; but ice, and water at 50° C. were recognised everywhere above the lower third of the forearm.

By August of the same year, sensibility to prick and to the extremes of temperature had further increased, but the loss of light touch was unaltered. By March, 1904, prick was appreciated everywhere, and even sensation to light touch had returned, excepting over the palm and dorsal aspect of the little and ring fingers. The palmar surface of the fingers could not be tested in consequence of the contracture. The biceps, triceps, supinator longus and flexors, and extensors of the wrist and fingers reacted to the interrupted current; even the wasted remains of the thumb muscles flickered under the application of an unusually strong interrupted current.

The lesion, which caused this extensive paralysis of motion and sensation, must have been situated on the distal side of the point where the posterior thoracic (n. thoracalis longus) comes off from the fifth, sixth and seventh cervical nerves to supply the serratus magnus. The nerve to the rhomboids was unaffected, but the conductivity of the nerves to the pectorals and to the latissimus dorsi was destroyed. Thus, the injury must have torn the brachial plexus between the point where the long thoracic and the suprascapular nerves are given off. The nerves forming the lower trunk must have been injured to such a degree that no form of cutaneous sensation could reach the central nervous system, excepting through the lesser internal cutaneous. Partial paralysis of the cervical sympathetic is accounted for by injury to the branch given off from the first dorsal nerve, or interference with the sympathetic when it lies on the neck of the first rib.

In all previous instances, destruction of one or more nerve trunks always caused a loss of sensibility more extensive to light touch than to prick. In this case, all forms of cutaneous sensation were abolished over the same

area; the upper limit was a firm line even in the neighbourhood of the acromion, where considerable overlapping occurs between the various peripheral nerves.

Cases of this kind reveal the physiological constitution of the brachial plexus. But they are rare; for its trunks or cords alone are injured in but a small percentage of the lesions of the plexus. The majority resemble more closely the following case, where not only the cords, but also the nerves arising directly from them had been damaged.

Case 51.—*Fracture of the neck of the scapula with injury to the circumflex, the ulnar and the internal cutaneous nerves.*

On June 25, 1901, George B. was admitted to the London Hospital under the care of Mr. Jonathan Hutchinson, jun., for paralysis of the left arm and hand. An iron girder had fallen on to his shoulder on October 4, 1900, fracturing the neck of the scapula, and causing so much local injury that the nervous lesion was overlooked. The onset of the loss of sensation could not be dated, but in January, 1901, he first noticed that his arm was wasted.

The condition of his arm in July, 1901, was as follows: The deltoid and biceps were wasted and completely paralysed; the triceps acted poorly, and was diminished greatly in volume. All the interossei and muscles of the little finger were wasted and paralysed, but those of the thumb contracted normally. The deltoid, infraspinatus and biceps did not respond to the interrupted current, and contracted sluggishly to galvanism. The condition of the triceps was doubtful. All the muscles of the thumb reacted well, but no reaction was obtained from any other muscles in the hand.

Sensation was lost over the area shown in fig. 15 corresponding in the forearm and hand to an injury of the ulnar and internal cutaneous nerves just after they have left the brachial plexus. On the flexor surface of the forearm, the loss was co-terminous for all forms of sensation; but on the extensor surface there was a difference of nearly 2 cm. between the borders of loss to touch and to prick.

On the outer side of the arm, also over the region of the deltoid, sensation was altered within an oval area 14 cm. in length, and 6 cm. in breadth. Towards the upper and the

FIG. 15.

To show the insensitive areas in Case 51, caused by an injury which fractured the neck of the scapula. The area on the arm corresponds to the distribution of the circumflex. The loss of sensation on the forearm and hand is due to injury of the internal cutaneous and ulnar nerves.

posterior aspects, the borders of this patch were well defined, and the loss to prick corresponded in extent with the loss to light touch. But both the lower border and that on the anterior aspect of the arm were indefinite, the loss of sensation merging gradually into parts of normal sensibility. Moreover, the extent of this loss of sensibility to prick and to the extremes of heat and cold was materially smaller than that of the loss to light touch. Thus the relation between the loss of light touch and of prick was exactly that seen when a peripheral nerve is injured.

On July 17, 1901, Mr. Hutchinson explored the brachial plexus above the clavicle, and found no sign of any abnormality in the nerves or cords of which it is composed.

From the nature of the loss of sensation, both over the deltoid region and in the forearm, it is probable that in the main the injury lay on the distal side of the point where the nerves had combined to form the cords of the plexus. Fracture of the neck of the scapula must certainly have injured the suprascapular nerve, and also the circumflex. The internal cutaneous and ulnar nerves must also have suffered in consequence of the violence of the injury.

Chapter 6.—Loss of Sensation in the Arm from Division of Posterior Roots.

In every case we have brought forward so far, the loss of sensation has been caused by division of afferent nerve fibres on the distal side of the posterior root ganglion. To complete our knowledge of the distribution of sensation, it will be necessary to consider the results which follow injury to the posterior roots. For this purpose the consequences of disease are rarely, if ever, sufficiently definite. But during the last ten years, Sir Victor Horsley has occasionally divided the posterior roots for intolerable and obstinate pain. To his kindness in allowing us to examine the patients, in whom he has performed this operation, we owe the opportunity of completing this part of our subject.

Case 52.—*Excision of the fifth, sixth, seventh, and eighth cervical, and first and second dorsal posterior roots.*

Ellen E., aged 45, was admitted to the National Hospital, Queen Square, under the care of Dr. Beevor, in March, 1898.

FIG. 16.

To show the loss of sensation produced by division of six posterior roots (C. 5, 6, 7, 8, D. 1 and 2) in Case 52.

As the area insensitive to prick was of greater extent than that insensitive to light touch, the boundaries of the two areas are marked by a thick continuous and a thin dotted line respectively.

Thirteen years before she had cut her right forearm with a glass lamp shade, and ever since had complained of pain in the arm; portions of various nerves were excised on fourteen occasions. Of the condition of sensation before the nerve roots were divided, we are unable to speak from personal observation. However, all who saw her agreed that, whatever loss of sensation may have been present ceased a few inches above the wrist.

On May 31, 1898, Sir Victor Horsley opened the dura mater, and excised the fifth, sixth, seventh, and eighth cervical, and first and second dorsal posterior roots. She recovered perfectly from the operation, and when seen by one of us on August 26, was bright and cheerful and free from pain. Sensation to prick was lost over the whole of the forearm and hand, and over the greater part of the arm, as shown in fig. 16. Cotton-wool was appreciated over part of this area, and the loss to light touch was less extensive than loss to prick everywhere on the arm. Whilst the border of the area insensitive to prick was extremely definite, that of the loss to light touch merged gradually into parts of normal sensibility. Water at 50° C. and ice were not appreciated over the analgesic area.

Here the extent of the skin insensitive to prick exceeded considerably that insensitive to light touch. The following case shows the remarkable behaviour of this area when tested with various degrees of temperature.

Case 53.—*Division of the fifth, sixth, and seventh cervical posterior roots.*

F. M., a woman of 31, had suffered from obstinate pain in the right arm for several years. In February, 1902, Sir Victor Horsley opened the spinal canal and divided the fifth, sixth, and seventh cervical posterior roots.

She was seen by one of us on May 15, 1905, and on several subsequent occasions, when the conditions were unusually favourable to careful examination. On account of her great intelligence and remarkable trustworthiness, the sensory observations made on this patient, particularly with regard to her sensibility to temperature, were of peculiar value.

The area on the arm and forearm insensitive to cotton-wool and the extent of the analgesia are shown on fig. 17.

This loss of sensation is the result of division of the posterior roots. The sensory condition of the hand will be neglected, for it was complicated by operations on the peripheral nerves, both

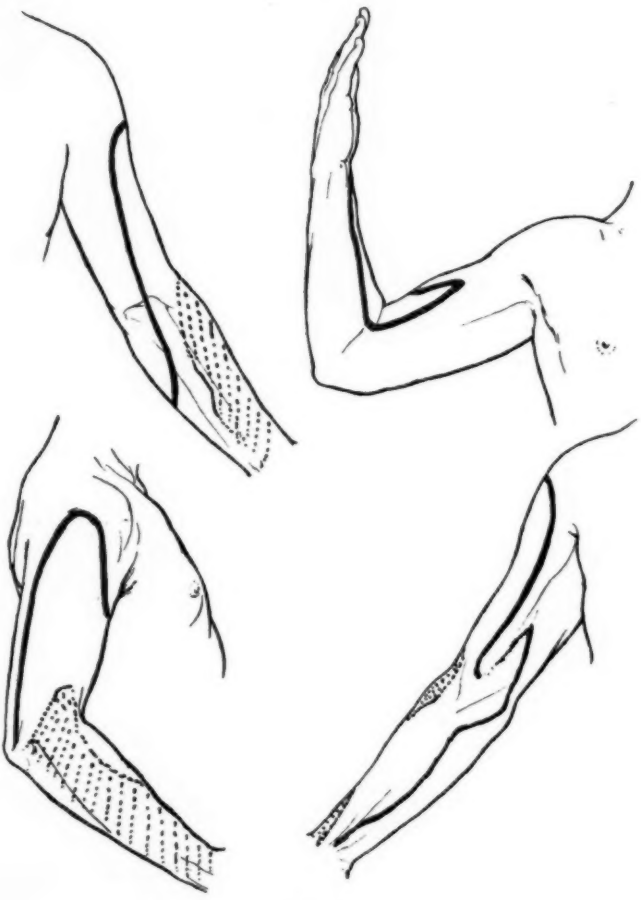


FIG. 17.

To show the upper border of the area insensitive to prick, and to the more extreme degrees of heat and cold in Case 53. The extent of the loss of sensation to light touch and to the intermediate degrees of heat and cold was smaller than that of the analgesia, and thus an area of dissociated sensibility was produced, fully described in the text. The dark line encloses the parts insensitive to prick; the dotted area corresponds to the loss of sensation to light touch. The hand is not included as its sensory condition was complicated by division of several peripheral nerves.

at the wrist and in the palm. In the previous instance cited in this chapter, the area insensitive to prick greatly exceeded in extent that of the loss to light touch, particularly over the outer aspect of the arm. A similar area sensitive to cotton-wool but insensitive to prick was found in Miss M.; it measured 7 cm. in the longitudinal, and 7·5 cm. in the transverse axis of the limb. In addition, a large part of the radial half of the flexor surface of the forearm was in a similar condition of sensibility, analgesic to prick, but sensitive to stimulation with cotton-wool.

Tested with the compasses over the deltoid region, there was little difference between the two sides. With the two points 4 cm. apart, applied longitudinally to the arm, she answered correctly every time on the sound side; but, on the affected side, the record was as follows: $\frac{1}{2}\left|\frac{8\text{ R. }2\text{ W.}}{10\text{ R.}}\right.$. At 3 cm. the threshold had been obviously passed on both sides. Thus she showed little difference in her power of discriminating two points on similar parts of the two arms, although the area to which they were applied on the affected side was entirely insensitive to prick.

Sensation to pressure was retained everywhere above the wrist, and the vibrations of the tuning-fork were appreciated both on the forearm and arm.

It is, however, to the reaction of this patient when stimulated with heat and cold that we wish to draw particular attention. Over the deltoid region on the affected arm, she could tell the difference between 38° C. and 25° C., saying that the first was warm, the second cool. But she was unable to recognise any difference between ice and water at 65° C.; 20° C. was distinctly cold, but ice in comparison was said to be neutral. The lowest temperature she recognised lay between 15° C., which was not appreciated, and 18° C., which seemed to her undoubtedly cool. Her sensations of warmth ranged from about 35° C. to 55° C.; all specific sensation ceased at this temperature, and the stimulus was appreciated as a touch only. When 55° C. and 40° C. were compared, the latter appeared more definitely warm, and her answers were more certain with the lower than with the higher temperature.

The condition of the area of dissociated sensation on the forearm was, in principle, the same, although in consequence of the general diminution of sensibility it could not be so minutely explored. Here also ice and water at 65° C. were not appreciated, but 21° C. and 38° C. were called respectively warm and cool.

From these two cases, and from others where the lesion was less certainly determined, it would seem, that division

of several posterior roots abolishes sensation to prick over an area larger and more sharply defined than that which becomes insensitive to light touch. Moreover, this insensibility to prick is accompanied by an inability to appreciate temperatures below 15° C. and above 60° C., although 40° C. and 23° C. may appear definitely warm and cool.

Chapter 7.—Nerve Supply of the Lower Limb.

§ 1.—*The Sole of the Foot.*

The nerves of the lower limb are much less frequently injured than those of the arm and hand, and most of the injuries fall either upon the sciatic or upon the external popliteal. Wounds, that divide the nerves to the sole of the foot in the neighbourhood of the ankle, are so uncommon that it is impossible to determine the distribution of the internal and external plantar; but the following instance shows in a remarkable way the nature and extent of the sensibility supplied by the posterior tibial nerve.

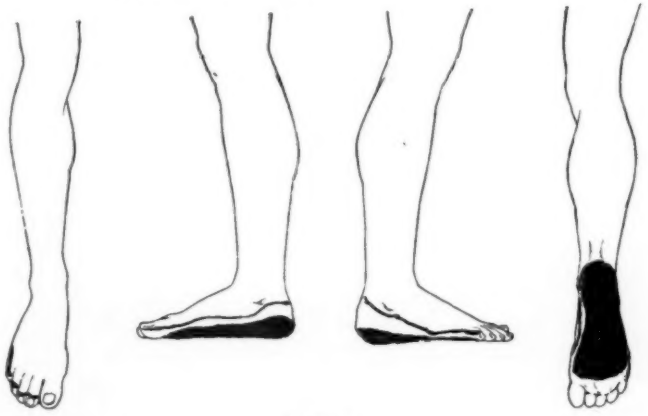


Fig. 18.

To show the area of cutaneous insensibility produced by division of the posterior tibial nerve (Case 54). Before the operation on August 15, 1902, the whole of the parts enclosed by the single line were insensitive to light touch, and to the minor degrees of heat and cold. After the operation the loss of sensibility to these stimuli remained unaltered, but the parts in black became insensitive to all cutaneous stimuli.

Case 54.—Division of the posterior tibial nerve at the ankle.

On May 16, 1901, J. T., while serving in South Africa, was shot through the right leg. The foot became "numb" and useless at once, but fourteen days later "feeling" came back. This return of sensation was associated with so much pain in the sole of the foot that the condition of the nerve was explored from the popliteal space, two months after the injury. He returned to England on August 22, and was sent to Devonport Hospital. There the posterior tibial nerve was divided just behind the internal malleolus, "in order to stop the swelling of the foot," and in consequence the whole sole became "numb."

In August, 1902, he came under the care of one of us at the London Hospital. The scar caused by the entry of the bullet lay just anterior to the tendon of the biceps femoris, 3 ins. (7·5 cm.) above its insertion; the wound of exit was 4 ins. (10 cm.) above the head of the tibia over the inner group of hamstring muscles. In the centre of the popliteal space was a well-healed surgical scar, a relic of the first operation, and behind the internal malleolus lay another scar, $1\frac{1}{4}$ ins. (3·5 cm.) in length, due to the operation in Devonport Hospital.

All the muscles below the knee reacted to the interrupted current, but the only movement of which they were capable was extension of the foot.

He complained that his foot was sore when he put it to the ground, and that this prevented him from walking.

The right sole was entirely insensitive to touch with cotton-wool, a stimulus which he easily appreciated over the whole of the normal foot. Sensibility to prick was nowhere lost, but, wherever light touch was defective, a prick caused increased discomfort, and was associated with a sensation of pins and needles. The whole of this area was insensitive to water at 15° C. and at 40° C., but water at 50° C. was said to be "very hot," and ice produced a sensation of numb, tingling cold. Over the sole of the right foot, the points of the compasses could not be discriminated when separated for 6 cm., whilst on the sound foot he made two mistakes only when they were 2 cm. apart.

We concluded from the physical signs that in this case the bullet had injured the sciatic nerve just above the popliteal space. Sensibility to pain was probably abolished for a few weeks only, and then, on the way to recovery, the foot became over-sensitive to all painful stimuli. Gradually the nerve regained its power

of conduction, and the muscles their normal reaction. But meanwhile, in consequence of division of the posterior tibial nerve, the sole of the foot had become insensitive, and he was in a worse position than he would have been without the operation.

On August 15, 1902, Mr. Barnard cut down on the structures behind the internal malleolus. A mass of firm fibrous tissue was exposed, and when this was dissected away, the two ends of the nerve were seen, the upper a bulbous mass and the lower spread out over, and closely adherent to, the vein. The nerve was dissected with difficulty from the vein, and when completely free was found to consist of an upper and a lower end connected by dense fibrous tissue. This intervening tissue was incised at several points, until the normal fibres of the central end were exposed. The distal end of the nerve was treated in a similar way until nerve fibres in considerable number became visible. The two ends of the nerve were then united together.

After this operation all pain disappeared, the extent of the loss of sensation to light touch remained unaltered, but sensibility to prick was lost over a wide extent of the sole (fig. 18). Over the whole of this area all degrees of temperature were unappreciated. When passing from normal to affected parts of the foot, minor degrees of temperature, such as 20° C. and 40° C., were no longer appreciated as soon as the border for loss to light touch was passed.

This case shows that the posterior tibial nerve supplies the sole of the foot with all forms of cutaneous sensibility. On the inner side, the border at which sensibility ceases is a well-defined line identical for all forms of sensation. But over the outer side, both the area of loss of sensation to light touch and that of the analgesia merge gradually into parts of normal sensibility, the loss of light touch exceeding in extent that of the loss to prick. From their plantar aspect, the toes were insensitive to light touch, but remained sensitive to prick.

Here also, as in the hand, recovery of sensation after complete division of the nerve began with a return of sensibility to painful stimulation, and to ice, and water at 50° C. The parts affected remained insensitive to light touch and to minor degrees of heat and cold, and two points could not be differentiated, even when separated to a distance of 6 cm.

That this return of sensibility was not due to substitution from the surrounding nerves is shown by the complete loss of all sensation produced by again dividing the affected nerve in order that its two ends might be sutured together.

§ 2.—*Loss of Sensation produced by Injury to the Nerves of the Leg.*

Division of the external popliteal nerve, below the point at which its lateral cutaneous branch is given off, causes loss of sensibility to light touch over a considerable portion of the outer side of the leg and over the whole of the dorsum of the foot (fig. 18, A). Within these limits sensibility to prick is evidently diminished, but is nowhere lost entirely, except over the dorsum of the foot (fig. 18, B). These figures, illustrating the loss of sensation produced by division of the external popliteal, were obtained from the following case.

Case 55.—*Injury to the external popliteal; resection and suture of the nerve.*

Joseph B. was admitted to the Poplar Hospital, under the care of Mr. Rigby, in July, 1900, with a compound comminuted fracture of the left tibia and fibula. Whilst falling, the right leg turned under him and he sustained a slight wound over the external condyle of the right femur. This wound healed rapidly, but three weeks after admission the patient was found to show signs of paralysis of the right external popliteal nerve. In spite of massage, the leg was still paralysed when he first came under our notice in October, 1901. Mr. Rigby therefore explored the nerve at the site of the injury and found it hard and firm, embedded for a distance of $1\frac{1}{2}$ ins. (4 cm.) in fibrous tissue; it had evidently been partially ruptured, and the upper end was bulbous and united to the lower portion by a strand of fibrous tissue. An inch and a half (3·75 cm.) was excised and the two freshened ends were reunited with silk sutures.

The paralysis of motion and sensation was in no way increased by this operation, proving that the pre-existing condition was due to complete functional division of the nerve.

The whole anterior tibial group of muscles (tibialis anticus, extensor longus digitorum and extensor hallucis), together with the peronei, were paralysed and had lost their reaction to the interrupted current. The flexor muscles of the toes and the muscles of the calf acted well.

The loss of sensation to light touch and to the painless interrupted current, shown on fig. 18, A, was bounded towards the shin and on the inner side of the dorsum of the foot by a definite line, but above, merged gradually into parts of normal sensibility. Sensation to prick was disturbed over an area of smaller extent (fig. 18, B), but the boundary on the inner side of the dorsum of the

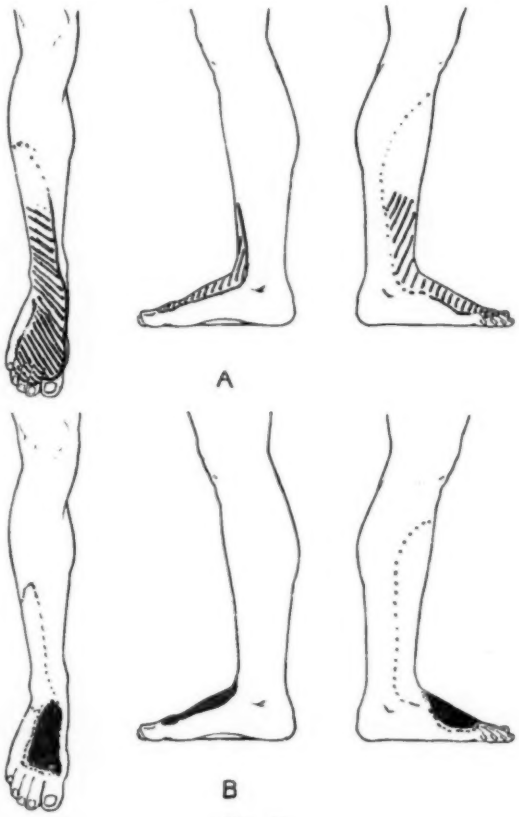


FIG. 19.

To illustrate Case 55.

A shows the extent of the leg insensitive to light touch, and the intermediate degrees of temperature after division of the external popliteal below its lateral cutaneous branch. The area of complete insensibility is shaded.

B shows the extent of loss of sensation to prick. The area of total analgesia is marked in black.

foot coincided with that of loss of light touch. Ice and water above 50° C. were not appreciated over the analgesic area, and he was unable to discriminate minor degrees of heat and cold over those parts where sensibility to light touch was destroyed. Deep touch and pressure were recognised everywhere over the affected parts. Over the dorsum of the sound foot, he could appreciate the two points of the compasses correctly when 4 cm. apart; at this distance he failed entirely over a similar part of the affected foot.

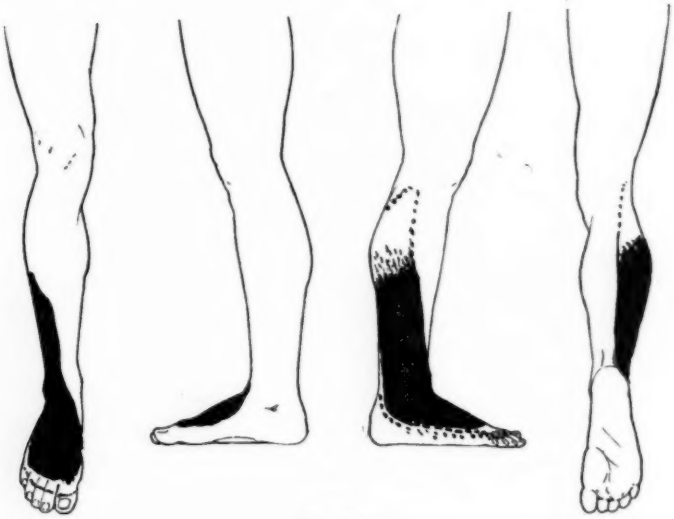


FIG. 20.

To illustrate the loss of sensation produced by division of the external popliteal above its lateral cutaneous branch (Case 56).

Total cutaneous insensibility is marked in black; this area merges above and below into parts sensitive to prick, but insensitive to light touch. The loss of sensation to light touch is enclosed in a dotted line. Above and on the outer side of the foot this area of loss to light touch merges into parts of normal sensibility.

When the external popliteal is divided below the origin of its lateral cutaneous branch, the posterior (sural) border of the loss of sensation is always ill defined in contrast to the astonishing definiteness of the anterior border. But when the continuity of the whole of this division of the sciatic is destroyed above the point where the lateral branch

is given off, the posterior border in the calf becomes as definite as that on the shin (fig. 20).

Case 56.—Complete division of the external popliteal nerve above the origin of its lateral branch.

On December 25, 1901, whilst serving in South Africa, Charles G. was shot through the right thigh with an explosive bullet. He fell and at once discovered that he could not move his leg.

When we saw him at the Royal Victoria Hospital, Netley (March 26, 1902), the wound of entry on the posterior aspect of the thigh 5 ins. (12·5 cm.) above the centre of the popliteal space had healed. On the outer surface of the thigh was a triradiate scar nearly 4 ins. (10 cm.) from end to end, in the centre of which lay a small area not completely healed.

The anterior tibial and peroneal groups of muscles were paralysed, much wasted, and did not react to the interrupted current. The foot could be inverted and the toes flexed; the calf muscles, though somewhat wasted, contracted strongly and reacted to the interrupted current.

Sensibility to light touch was lost within the dotted line on fig. 20. It will be evident how closely its anterior and posterior borders correspond with the extent of the loss of sensation to prick marked in black. The upper border and the border on the outer side of the foot were indefinite, merging into parts of normal sensibility.

Wounds of the thigh dividing the sciatic nerve completely are so rare that we are compelled to construct the full picture of the consequences of such an injury from a comparison of several cases, not one of which is in itself entirely satisfactory.

Thus, in the case of William B. (No. 57[1]), where the injury was caused by a bullet wound of the nerve in the region of the buttock, muscular paralysis was complete below the knee. But we did not see him until ten months after the injury, and by that time sensation had already begun to improve. Yet an examination of fig. 21 shows the well-marked border on the anterior surface of the leg, and on the inner aspect of the foot, produced by a complete lesion of the great sciatic.

[1] *Vide* Appendix, p. 396.

The full extent of the loss of sensation to light touch, produced by division of the great sciatic, is shown on fig. 22. But here, again, although all the muscles supplied by the great sciatic were absolutely paralysed and the anæsthesia to light touch was of the full extent, sensibility to prick had begun to return on the outer side of the leg.

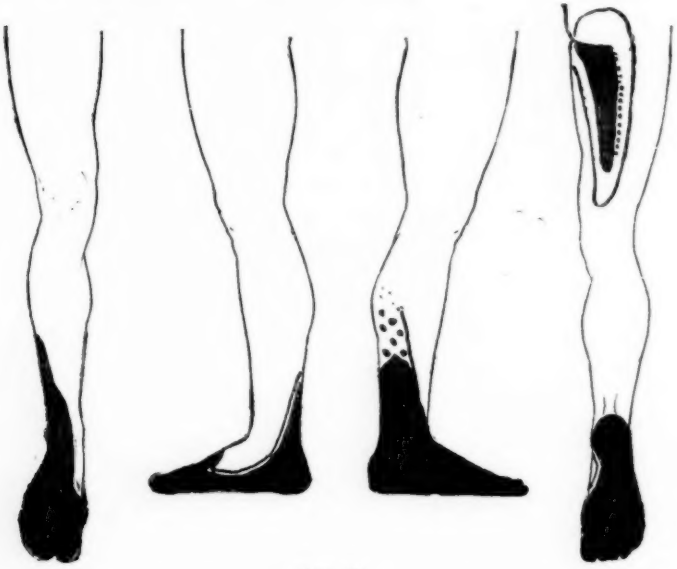


FIG. 21.

To illustrate Case 57. The loss of sensation, produced by injury to the small sciatic, is shown on the thigh and buttock, total insensibility to all cutaneous stimuli being shown in black. The extent of the loss to light touch is shown by a single dark line.

Below the knee the loss of sensation was caused by injury to the great sciatic nerve, which had already begun to recover, the two forms of sensibility returning together, as usual, with partial injuries.

Case 58.—*Complete division of the great sciatic nerve in the thigh.*

On May 29, 1896, Benjamin A. was stabbed in the thigh during a brawl. About the middle of the back of the thigh was an incised wound which had completely divided the semitendinosus muscle. He was collapsed, having lost much blood. The wound was united, after suture of the muscle, and healed well.

As soon as the wound had healed, all the signs were discovered of division of the great sciatic nerve. All movements of the foot and ankle were impossible, and sensation to touch and to prick was lost over the outer aspect of the leg and over the dorsum and sole of the foot.

On July 30, 1896, the condition of the nerve was explored by Mr. Openshaw. It had been entirely cut across, and the two ends were united by fibrous tissue; the two ends were freshened and reunited with silk sutures.

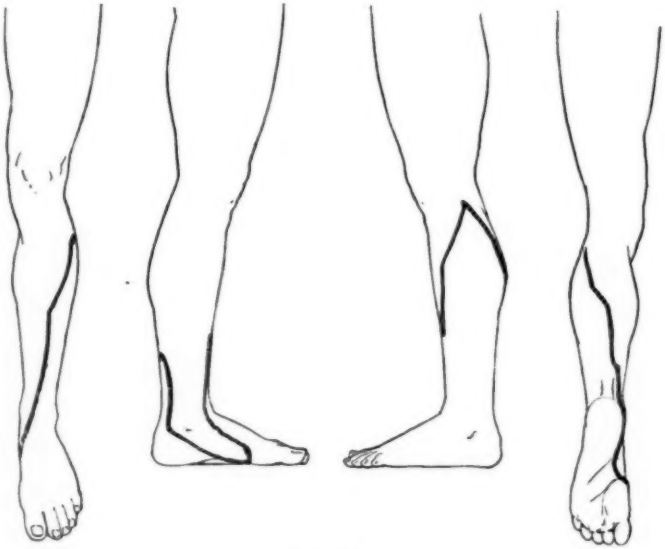


FIG. 22.

To show the extent of the area that became insensitive to light touch in consequence of division of the great sciatic in the thigh (Case 58). The extent of the analgesia, which occupied the whole foot below the level of the ankle, has not been inserted, for the sensibility to prick had recovered considerably before we first saw this patient.

He was first seen by one of us in February, 1899, nearly two years and a half after this operation. All the muscles supplied by the sciatic were paralysed and failed to react to the interrupted current. The extent of the loss of sensation to cotton-wool is shown on fig. 22. The foot and a small part of the outer aspect of the leg were insensitive to prick, and to heat and cold but,

as this form to sensibility had obviously begun to improve, the insensitive area has been omitted from fig. 22.

The most complete loss of all forms of sensation produced by a wound of the great sciatic which has come under our notice was in the case of H. N. (No. 59), wounded on February 25, 1902, whilst serving in South Africa. When we first saw him, five months later, of the muscles below

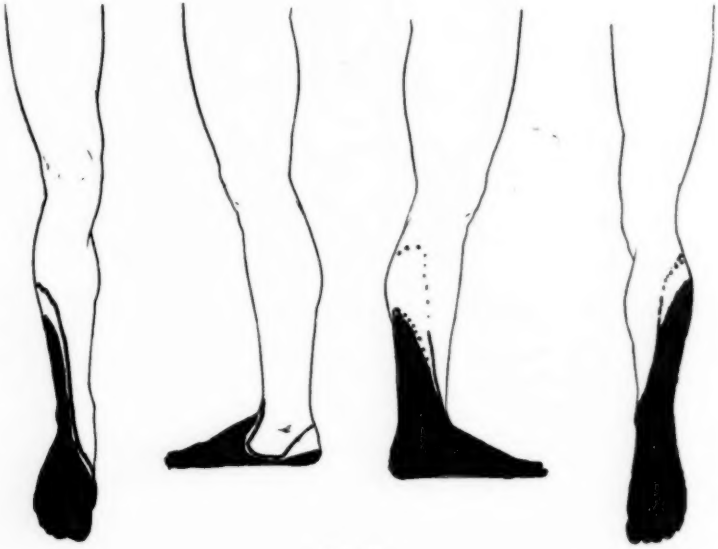


FIG. 23.

To illustrate the loss of sensation in Case 59. The area insensitive to light touch, and to the intermediate degrees of temperature, is enclosed in a dark line, dotted where the border is not well defined. The parts insensitive to prick and to all forms of temperature stimulation are coloured black.

the knee, the gastrocnemius alone was acting, and all of them with this exception failed to respond to the interrupted current. The extent to which sensibility was lost in this case is seen on fig. 23, which shows the nature of the anterior and posterior borders, and the considerable loss on the inner aspect of the foot.

Case 59.—*Bullet wound of the thigh, injuring the great sciatic nerve.*

Henry N., aged 22, was shot through the right thigh on February 25, 1902, whilst serving as an Imperial Yeoman. He was removed to hospital, and the wound healed in three weeks. After his arrival at the Royal Victoria Hospital, Netley, on July 3, the leg was massaged daily, and when we first saw him, on August 2, 1902, he had begun to improve.

The bullet had entered on the posterior surface of the thigh, 4 ins. (10 cm.) above the centre of the popliteal space; the wound of exit lay on the anterior and internal aspect, $1\frac{1}{2}$ ins. (4 cm.) above the patella. Immediately under the wound of exit, a well-defined hole had been drilled through the bone by the bullet.

All the muscles of the thigh were acting; but below the knee, only the gastrocnemius contracted voluntarily, and that feebly. This muscle reacted to the interrupted current, and the reaction to the constant current was normal. No other muscles below the knee reacted to the interrupted current, and both the anterior and external groups responded more readily to the anode than to the kathode..

Light touch was not appreciated over the area shown in fig. 23, and it will be seen how closely this loss of sensation coincided with that to prick, excepting only at its proximal border.

§ 3.—*The Nerve Supply of the Leg deduced from Residual Sensibility.*

So far we have attempted to determine the loss of sensation produced by division of the main nerve trunks of the leg. But loss of sensation does not reveal the full cutaneous distribution of an injured nerve. This we can only learn by observing the limits of the area which remains sensitive when all the surrounding nerves have been destroyed. In the previous section, each case was arranged to show the loss of sensation caused by injury to a particular nerve. Here the same cases will be regarded from the opposite aspect; division of the posterior tibial will be cited to reveal a portion of the boundary of the external popliteal, and the limits of the internal saphenous will be mapped out by a consideration of the consequences that followed injury to

the great sciatic. Where the boundaries for sensation to light touch and to prick coincide, this method of residual sensibility produces results that can be easily comprehended. But, where these borders are widely separated, the results will appear at first complex and difficult.

We shall therefore begin with a consideration of the boundaries of the internal or long saphenous, a nerve whose

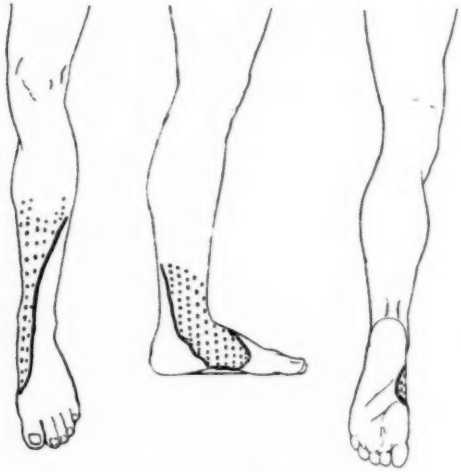


FIG. 24.

To show the area supplied by the internal saphenous, deduced from the residual sensibility after complete division of the sciatic nerve. The boundaries of this area are almost co-terminous, whether light touch or prick be used as the stimulus. The extent of residual sensation in the direction of the great toe varies in different cases.

limits are easily determined by this method. When conduction in the great sciatic is completely destroyed, the long saphenous alone supplies sensation to those parts which remain sensitive over the lower half of the leg and inner side of the foot. By comparing the cases where the internal saphenous alone supplies sensation to the leg, the nerve is

found to innervate for light touch and for pain the parts shown on fig. 24. On the front of the leg, the distribution of the two forms of sensibility closely agrees, but on the inner side of the foot and over the calf of the leg, the fibres that subserve sensibility to light touch, are less widely distributed than those which conduct sensation of prick.

In attempting to estimate the full distribution of the external popliteal, of its lateral cutaneous branch, or of the external saphenous, it must be remembered that, as far as light touch is concerned, these three nerves form a group supplying the post-axial half of the leg. The boundaries of the area they supply on the shin and the calf are extremely definite, but all borders which are not coincident with these lines are ill defined. Whenever the limits of any one of the constituent branches coincides with one or other of these lines, the boundary is sharply defined, at every other part its borders merge gradually into the parts supplied by other members of the group. This makes it impossible to map out the post-axial half of the leg into well-defined areas, each innervated by one of the branches which forms the constituent elements of its nerve supply. The constitution of the external saphenous is an additional hindrance to analysis of this part of the leg. For destruction of the whole external popliteal will remove all the sensibility from the outer side of the foot which depends on the integrity of its peroneal communicating branch, whilst that part innervated by the tibial communicating will be rendered insensitive by division of the internal popliteal.

Again, to complete the analysis of this part of the leg a case of complete division of the internal saphenous is wanted, that we may observe the full extent of skin supplied by the sciatic nerve.

On fig. 25 is shown the full distribution of the lateral cutaneous branch obtained by subtracting the area of total loss of sensibility due to division of the external popliteal below its lateral branch, from the complete area supplied by the great sciatic. Both for touch and for prick the territory of this nerve seems to be bounded by a sharply defined border over the shin and over the calf. But towards the

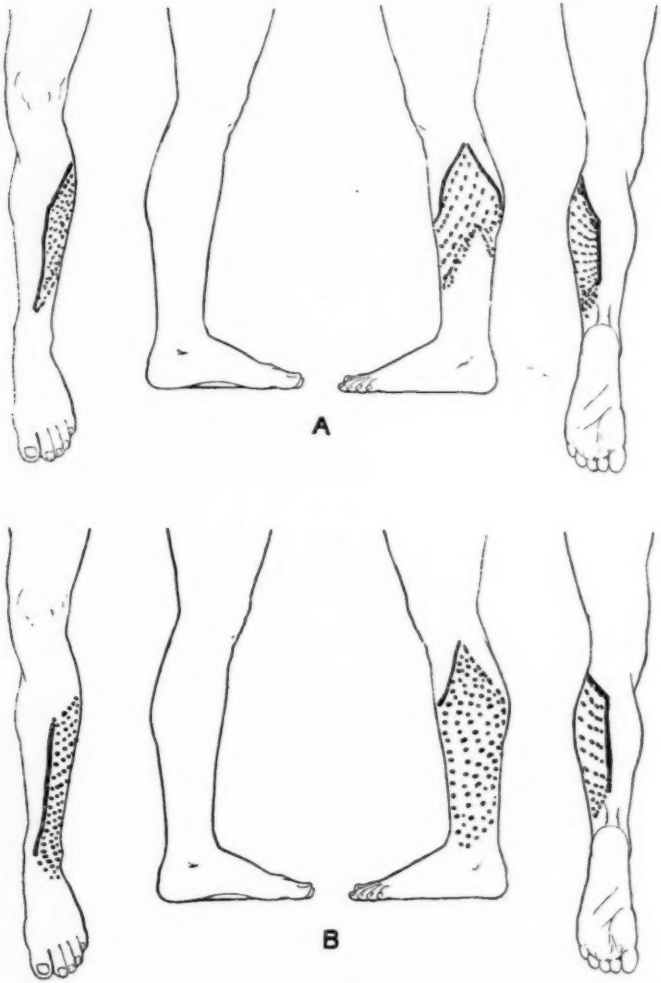


FIG. 25.

To show the full extent of skin supplied by the lateral cutaneous branch of the external popliteal nerve. The upper figure (A) shows the area supplied with sensibility to light touch; the lower figure (B) shows the extent supplied with sensibility to pain.

periphery of the limb, its limits are extremely ill defined; a large part of the outer aspect of the leg is shared by this branch in common with the external popliteal. As usual in such circumstances, the extent of skin supplied by the lateral cutaneous with sensibility to prick is greater than that for light touch and the minor degrees of heat and cold.

The full supply of the external saphenous, as far as we have been able to determine it, consists of an ill-defined strip on the outer aspect of the foot. The area supplied by this nerve merges at every point into parts innervated by neighbouring branches. It is nowhere bounded by a well-defined border. Over the outer aspect of the foot it merges into parts supplied by the external popliteal on the one side, by the posterior tibial on the other. Behind, as far at any rate as sensation to prick is concerned, it overlaps the internal saphenous. The method of residual sensibility confirms the opinion gained from dissection that this nerve is only a temporary conjunction of fibres to complete the supply of the outer side of the foot.

We require a case of division of the internal saphenous to complete our knowledge of the full distribution of the posterior tibial. This nerve supplies sensibility to light touch over the dorsal aspect of the toes, from the tip as far down as the first interphalangeal joint, except in the little toe; sensibility to prick extends as far as the base of the toes. The distribution on the outer side of the foot can be learnt only from a case where both external popliteal and external saphenous have been divided, and no such case has yet come under our notice.

We have been able so far only to show the way for future research along the lines that alone will reveal the full cutaneous distribution of the peripheral nerves of the leg. By the method of residual sensibility we have mapped out the whole of the distal portion of the internal saphenous and described in part the boundaries of the external saphenous, the posterior tibial and the lateral cutaneous branch of the external popliteal.

But, in order to complete our knowledge of the borders of these nerve areas, it will be necessary to obtain instances

where the internal saphenous nerve and the internal popliteal have been separately divided.

Chapter 8.—Deep Sensibility.

If all the nerves supplying a portion of the skin be divided, and at the same time the muscular branches remain uninjured, that part will become insensitive to all forms of superficial stimulation, but will remain sensitive to pressure. As in the majority of our cases the injury was accidental, both muscular and cutaneous fibres were divided together. But even these accidental lesions, if compared the one with the other, can be made to yield certain well-defined principles concerning the nature, capabilities and distribution of deep sensibility.

In one case which came under our care (Case No. 47[1]) the radial and external cutaneous nerves had been divided by a transverse wound running round the outer side of the forearm. The skin over the back of the thumb and the radial half of the back of the hand were insensitive to light touch, to prick, and to all forms of heat and cold. But over the whole of this area pressure was at once appreciated. Even cotton-wool, if rolled up tightly, and particularly when applied suddenly and forcibly to the skin, caused a definite sensation. Touch with the blunt head of a pin was localised with remarkable accuracy, but our patient could not distinguish pressure with the head from a prick with the point of a pin. Even when separated to 5 cm. and applied transversely, the compasses were appreciated only as a single "push" or focus of pressure. Any stimulus dragged across the surface so as to move the skin over underlying parts was at once appreciated. A piece of cotton-wool rolled up into a pledget applied to the skin with some force produced a definite sensation. But if the skin was lifted the same method of stimulation entirely failed to evoke any response, a proof that whatever sensation had been previously present was due to the underlying structures.

Thus, if a part is deprived of all its cutaneous nerves it

[1] Reported in full in the Appendix (*vide* p. 327).

becomes entirely insensitive to light touch, to prick and to all forms of temperature, but remains sensitive to any stimulus which jars the skin, however lightly. The compass points applied simultaneously are appreciated as a single impact, however far apart they may be; applied successively they usually produce a sensation of pressure in two places even when separated by a distance of only two centimetres. These characteristics were even better seen in the case of one of us in whom the same two nerves were divided experimentally at the elbow. In both instances, the accuracy and quickness with which even slight degrees of pressure were appreciated and localised came to us as an entirely unexpected fact. Both the trained observer and J. S. (Case 47) could appreciate and localise every stimulus commonly used as a test for light touch, and all the surgeons who examined the former patient were certain that light touch had not been destroyed by the operation. The touch of a finger, stimulation with the point of a pencil, a pen, or a tooth-pick, are tests for deep sensibility, and can be appreciated even when all the nerves to the skin have been destroyed. Even a touch with a camel's hair brush evokes a sensation from parts in this condition if the brush is thick and is applied vertically to the plane of the skin.

So far the problem is simple and permits of a definite answer. Deep sensation is not materially affected by the destruction of all the nerves to the skin, and it must reach the central nervous system by fibres that run in other channels than the so-called sensory nerves.

But any attempt to discover by what means the deep parts receive this innervation is hampered by the accidental nature of the lesions that come under our observation, and by the complexity thus introduced into the experimental conditions. For so long as the sensibility of the skin is unaffected, it is impossible to investigate the sensation evoked by pressure. It is even difficult to determine with certainty the condition of the sense of passive position in the joints when superficial sensibility is perfect. The skin should be totally insensitive to all stimuli before deep sensation can be satisfactorily tested, a condition which greatly limits the possible opportunities of examination.

Since deep sensibility is not materially affected by complete destruction of the nerves to the skin, its presence must depend upon the existence of afferent fibres from one or more of the following structures—the muscles, the tendons, the periosteum, the bones, and perhaps the arteries.

Complete division of the median nerve renders the palmar aspect of the index and middle fingers, and occasionally part of the palm, totally insensitive to all those forms of stimulation which appeal solely to the nerves of the skin. The only muscles to which this nerve supplies fibres below the wrist are the opponens and abductor muscles of the thumb and the two radial lumbricales. These structures lie in a part of the hand which does not usually become insensitive to prick, to heat, and to cold in consequence of division of the median nerve, and such an injury occurring at the wrist should produce no change in the deep sensibility of the fingers or the palm. The following instance showed the correctness of this hypothesis.

Case 10.—*Complete division of the median nerve with no loss of deep sensibility in the palm or fingers.* (*Vide* Table I., p. 152.)

Mrs. W. thrust her right hand through a window, completely dividing the median nerve at the wrist. At the subsequent operation the palmaris longus was found to be the only other structure injured by the accident. All the tendons were intact, and the radial artery was not divided. The loss of sensibility to prick and to all forms of heat and cold was unusually extensive, occupying a considerable portion of the radial half of the palm and the whole of the palmar aspect of the thumb and of the index and middle fingers (*vide* fig. 3, J, p. 136). Over this area, excepting over the tips of the fingers, pressure with the head of a pin or any blunt object was appreciated and localised with surprising accuracy. But she was unable to recognise the difference between the point of a pin and pressure with the end of a cylindrical rod 1 cm. in diameter. Appreciation of passive movement at all the joints was perfect; when the terminal phalanx of either the index or middle finger was grasped laterally, and flexed or extended passively, she was able, though blindfold, to reproduce with accuracy in the corresponding finger of the

sound hand, the position into which the finger affected had been placed. The vibration of a tuning-fork (C 128) was recognised perfectly everywhere over the affected area.

From these observations we may conclude that destruction of those fibres of the median nerve, which run to the intrinsic muscles of the hand, makes no material difference to the deep sensibility of the palm and of the two proximal phalanges of the index and middle fingers. The deep structures in the palm receive their nerve supply, for the most part, from the ulnar nerve, and the flexor tendons or their sheaths must convey the afferent fibres of deep sensibility to the palmar aspect of the index and middle fingers. The tendons receive their nerve supply in the forearm, and if they are divided at the wrist any nerve fibres, which pass along them to reach the fingers, will be destroyed. Division of the tendons to the index and middle fingers should lead to loss of sensibility to pressure over the palmar aspect of these fingers, provided that the skin has been rendered totally insensitive by simultaneous destruction of the median nerve. Such a combination is not uncommon in wounds of the wrist, and the following instance shows that the result fulfils the presupposed consequences of such an injury.

Case 7.—*Division of the median nerve and of the tendons to the index and middle fingers. Loss of deep sensibility over the palmar aspect of these fingers.* (*Vide* Table I., p. 152, and fig. 3, A, p. 136.)

W. J. K. pushed his hand through a glass door, dividing the median nerve and all the tendons lying on the radial side of the wrist. At once he became unable to flex the index and middle fingers, and the whole of their palmar aspect became insensitive not only to prick, to heat and to cold, but also to pressure. On their dorsal aspect pressure was everywhere appreciated, in spite of the insensibility of the two terminal phalanges to all skin stimuli. Pus formed around one of the deep stitches by which the nerve had been united. This delayed the return of all forms of skin sensibility to such an extent that eight months after suture the insensitive area was almost as extensive as before the operation. But in this interval the patient had regained the power of

flexing the index and middle fingers; the long tendons had evidently united. Pressure was now appreciated everywhere and localised with accuracy over the palmar aspect of the index and middle fingers. At this time the motor fibres of the median nerve had not recovered, for the thumb could not be abducted or opposed, and the abductor and opponens pollicis did not react to the interrupted current. Thus, the restoration of deep sensibility to the index and middle fingers was probably due to fibres conducted by the flexor tendons, fibres they had received somewhere in the forearm above the site of the injury.

All the intrinsic structures in the palm of the hand are supplied by the ulnar and median nerves;[1] all the flexors to the fingers receive their nerve supply in the forearm. If, therefore, it were possible to divide both nerves at the wrist, without dividing the tendons, some sensibility to pressure should still remain in the fingers and palm.

Such an isolated destruction of the median and ulnar nerves is extremely unlikely to result from any ordinary accident, and no such instance has come under our observation. For every injury, sufficiently severe to injure the two great nerves at the wrist, divided at the same time some of the tendons in their neighbourhood. We are, therefore, compelled to fall back upon a case where, at the time of the injury, the tendons were united, but the divided nerves were overlooked.

G. B.[2] (Case 28, Table III., fig. 4, B, p. 138) cut his wrist on September 24, 1902. The wound ran somewhat obliquely across the forearm from the ulnar to the radial side, crossing the central axis of the limb about 3·5 cm. above the fold of the wrist. The tendons were sutured and the radial artery ligatured at once; but no attention was paid to the divided nerves. The wound healed perfectly. Seven months later (April 16, 1903) he came under our notice because of the persistent loss of sensation. An exploratory operation revealed the following condition: The median nerve was completely divided, and its lower end had been united to one of the superficial tendons. The upper end of the ulnar nerve was bulbous and adherent to the tendon of the flexor carpi ulnaris; a thin strand of tissue ran from this bulb to the peripheral portion of the divided nerve. All the tendons had

[1] Possibly also by perforating fibres from the radial.
[2] *Vide* Appendix, p. 321.

united firmly. Both nerves were therefore freshened, and the ends joined with silk; the wound healed by first intention.

We were now face to face with almost exactly the conditions we desired. Both nerves were completely divided, and any tendons that had been severed by the original cut had now united. After this operation, rather more than one-half the palm on the ulnar side became totally analgesic; and yet, over the whole of this area, pressure was appreciated. Fuller observations were made in August, when the general condition of the hand was more favourable for testing. The extent of the palm insensitive to prick had diminished slightly, but was still of considerable size. Within this area, pressure was appreciated and localised with remarkable accuracy. Two compass points separated for a distance of 4 cm. were not discriminated when applied simultaneously, but if one point was allowed to touch the skin before the other, even by a fraction of a second only, the patient knew that he had been touched in two places. On successive contact he recognised the double touch without fail when the points were 2 cm. apart, and rarely fell into error even when they were 1·5 cm. distant from one another. The only part insensitive to deep touch was the whole of the palmar and the greater part of the dorsal aspect of the little finger, a loss of sensation which makes its appearance whenever the whole ulnar nerve is divided.

Complete division of both nerves at the wrist does not destroy the deep sensibility of the palm. But if, in addition, the flexor tendons are divided, pressure can be no longer appreciated over the area insensitive to prick.

Mrs. L. (Case 26, Table III., fig. 4, A, p. 138) fell with a jug in her hand, severing the median and ulnar nerves and all the tendons on the anterior aspect of the wrist. Sensation to prick, to heat and to cold was lost over a large part of the palm, and over the palmar aspect of all the fingers. The whole of this area of the hand was insensitive to pressure. This complete loss of sensibility to pressure contrasts in a striking manner with its retention in the case described above (No. 28), where the tendons were allowed to heal before any attempt was made to unite the divided nerves.

Division of the ulnar nerve produces results upon the sensibility of the palm that are even more complex and difficult to unravel. This nerve supplies in the forearm the

flexor carpi ulnaris, the flexor profundus digitorum, and almost certainly the tendons of the latter muscle inserted into the little and ring fingers. In the palm it sends branches to all the intrinsic muscles of the hand except the abductor, opponens, and outer head of flexor brevis pollicis, and the two radial lumbricales. But division of the ulnar nerve renders totally insensitive only a small part of the skin of the hand; the field of observation for deep sensibility is, therefore, restricted to the little finger and a strip on the ulnar side of the palm in front and behind. Any sensation from the deep parts in this region must pass through the ulnar nerve, whether it be due to fibres running with the two tendons, or to those supplying the muscles and connective tissue of the palm, or to the innervation of the bones and joints of the little finger. Complete division of the ulnar nerve at the elbow should therefore produce the same results as division of the nerve and tendons at the wrist.

In Case 19,[1] the ulnar nerve, where it lay in the groove behind the internal condyle, had become infiltrated with fibrous tissue in consequence of an old injury to the elbow. The diseased portion was resected, and the two healthy ends united. The total cutaneous insensibility which resulted was of considerable extent on both the dorsal and palmar surfaces of the hand (fig. 1, 1, p. 127). Over the whole of this area the patient was insensitive to pressure. He could not appreciate the vibration of a tuning-fork over the whole of the little finger, back and front, and was unable to tell into what position its phalanges had been placed passively. Thus, division of the ulnar nerve at the elbow, had abolished the appreciation of pressure over the area totally insensitive to cutaneous stimuli, and destroyed the sensibility of the bones, joints and periosteum of the little finger. This patient was still able to produce some movement of the little finger by means of the flexor sublimis, but the tendon of this muscle alone was unable to maintain even a trace of sensibility to pressure in the little finger.

In Case 83[2] part of the ulnar nerve had been resected in

[1] *Vide* Appendix, p. 309.
[2] *Ibid.*, p. 311.

the hope of curing the neuralgia which had followed an incised wound at the wrist. The nerve had been divided distal to the origin of its muscular branches in the forearm, but above the point where the branch is given off to the back of the hand. This operation abolished sensibility to pressure over the two terminal phalanges of the little finger in front and behind; the condition of the parts over the palmar aspect of the basal phalanx was doubtful.

Here the conditions were simple; the nerve lesion was known with certainty, and the clinical picture was not complicated by injury to other structures. It would seem from this case that division of the ulnar nerve, just above the wrist, can render the two terminal phalanges of the little finger insensitive to pressure, but does not necessarily abolish this form of sensibility over the palm or dorsum of the hand.

The flexor carpi ulnaris, the innermost tendon of the flexor sublimis and the ulnar artery were divided in addition in Case 14, without adding to the area insensitive to pressure; it occupied the two terminal phalanges of the little finger exactly as in the previous case. But in E. R. (Case 15, Table II., fig. 1, G, p. 127), where the same structures were divided with the addition of the palmaris longus, pressure was not appreciated over the whole little finger and extreme ulnar border of the hand. It is possible that division of the palmaris longus may have played an important part in the increased extent of this loss; but the innervation of the deep structures in the palm probably varies considerably.

Whenever the nerve is divided, together with a considerable number of tendons, the loss of sensation to pressure tends to coincide with the area of loss to all forms of cutaneous sensibility. The extent of the area of total cutaneous insensibility is always small, and the field available for investigation is therefore restricted.

But if this cutaneous field of total insensibility were increased from any cause, it would be possible to examine more fully the extent of the loss of sensation to pressure caused by division of the ulnar nerve together with the

flexor tendons of the wrist and fingers. In the following instance, where the median nerve was injured in addition to the above-mentioned structures, we obtained an approximation to these conditions. Sensibility to pressure was lost over the back and front of the little and ring fingers and over a considerable area on the palmar and dorsal surfaces of the hand. Vibration of the tuning-fork was not appreciated over the whole of the front of the little finger and over the two terminal phalanges behind. The sense of passive position was lost in all the interphalangeal joints of the little finger.

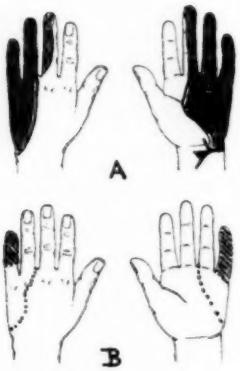


FIG. 26.

A shows the extent of the hand which became insensitive to light touch, to prick, to heat, and to cold in Case 60.

B, the deeply shaded area corresponds to the parts entirely insensitive to the vibrations of a tuning-fork, and the dotted line encloses the extent of insensibility to pressure produced by the lesion in Case 60.

Case 60.—*Division of the ulnar nerve, the tendons of the flexor carpi ulnaris and flexor sublimis digitorum, together with injury to the median nerve.*

M. G., aged 14, cut his left wrist with broken glass on November 13, 1904. The wound was explored six hours later by one of us and the ulnar nerve, together with all the tendons of the flexor sublimis digitorum and the tendon of the flexor carpi ulnaris were seen to be divided. The wound had partly

divided the median nerve on its ulnar aspect. Both nerves were sutured with catgut.

All cutaneous sensibility to touch, pain, heat and cold was abolished over the area shown in fig. 26, A.

He was unable to appreciate passive movements in the little and ring fingers. The vibration of a tuning-fork (C 128) was not perceived when applied over that part of the little finger shaded in fig. 26, B, whilst all sense of pressure was lost over the larger area enclosed within a dotted line.

All the intrinsic muscles of the hand were paralysed, and on November 23, 1904, did not react to the interrupted current.

On December 14, 1904, the abductor and opponens pollicis not only acted voluntarily, but had regained their reaction to the interrupted current.

On February 1, 1905 (80 days after suture), sensibility to prick and to the extremes of temperature had begun to return.

By March 8, 1905 (115 days after suture), he had regained sensibility to the vibration of the tuning-fork over the little finger, and the area insensitive to pressure had begun to decrease in extent. But all sense of passive movement was then absent from the little and ring fingers.

On April 5, 1905 (143 days after suture), the analgesia had been reduced to such an extent that it was no longer possible to examine with pressure for the loss of deep sensibility. The sense of passive movement was present in the metacarpo-phalangeal joints of both ring and little fingers, but was still absent from the interphalangeal joints.

From this point the patient disappeared and could not be traced. It was, therefore, impossible to determine the date at which all forms of deep sensibility were restored.

We have been able to prove that complete destruction of all the sensory nerves to the skin leaves the area they supply sensitive to pressure. This deep sensibility is evoked by any stimulus that displaces the subcutaneous structures, and when excessive, may cause pain. When heat and cold are applied over an area of total cutaneous insensibility, they are not appreciated, and two compass points cannot be discriminated even when separated widely, and yet the patient still retains considerable power of localising the point at which pressure is applied.

This sensibility is due to afferent fibres which run with the motor nerves and supply the muscles, tendons, fascia and

joints. Even division of both median and ulnar nerves at the wrist will produce little loss of deep sensibility, unless the tendons be divided at the same time.

Chapter 9.—Sensations of Temperature.

When one of the nerves of the hand is divided, it will be found that heat and cold are no longer appreciated over those parts that are insensitive to prick. But should the area of loss of light touch greatly exceed that of the loss of sensation to prick, as is commonly the case, ice or water at 50° C. will be found to produce a sensation of cold or of heat over the intermediate zone. And yet this intermediate zone, though sensitive to the more extreme degrees of temperature, has also suffered a change in sensibility; for water at 40° C., warm to the normal hand, and water at 22° C., easily appreciated as cold there evoke no response.

Thus, division of a peripheral nerve causes loss of sensibility to light touch and to temperatures between about 22° C. and 40° C. over a wide area of the hand, and over a smaller area, loss to prick accompanied by complete insensibility to all degrees of temperature. Such are the conditions immediately after a nerve has been divided.

During normal recovery we have shown that sensibility to prick is restored over the whole hand before that to light touch shows even the slightest return; and it may thus come about that for a considerable period the whole of the affected area of the hand remains insensitive to light touch, but sensitive to prick. This part of the hand has now reached a condition resembling that of the intermediate zone; heat above 50° C. and cold below 20° C. are everywhere appreciated, but the affected parts are insensitive to the milder degrees of heat and cold.

By the time this condition has been reached, the hand is half-way towards recovery, and it will be well to trace, more in detail, the steps by which sensation has been so far restored. At first the area of complete analgesia corresponded closely in extent with that of complete thermal anæsthesia. Any want in exact correspondence is probably

due to the greater intensity of the stimulus produced by a prick. The area of total loss of sensation to prick, to heat and to cold, is not sharply defined; it merges gradually into parts sensitive to all these stimuli. As a prick is relatively the most urgent and intense of these three forms of stimulation, parts of lowered sensibility will react to pain, although apparently entirely insensitive to heat and cold. Thus, the extent of the total loss of sensation to prick not infrequently appears to be somewhat less than that of the total loss to heat and cold.

As soon as sensation to prick begins to return, step by step it is followed by recovery of sensation to temperatures above 50° C. and below about 18° C. Occasionally sensibility to heat seems to lag somewhat behind that to cold and to prick. This is due partly to blueness and coldness of the affected hand, and partly to the comparative weakness of heat as a stimulus to parts of defective sensibility.[1]

But ultimately the hand becomes sensitive to prick, to cold (below 18° C.), and to heat (above 50° C.) over the whole area affected, either simultaneously or within a comparatively short interval from the commencement of recovery.

Up to this point, the loss of sensation to light touch remains exactly as on the first examination, and not infrequently weeks or months elapse, before it shows any sign of recovery. It is during this period that the affected area gives the most constant abnormal reactions to heat and cold. For, although the more extreme degrees of heat and cold are readily recognised, temperatures between about 22° C. and 40° C. are not appreciated, and a test tube containing water at 24° C. is not discriminated from one containing water at 38° C.

It will be noticed that we have defined the more extreme forms of temperature as above 50° C. and below 20° C., and from about 22° C. to 40° C. have been called intermediate degrees. It will be shown in a subsequent paper on the consequences of experimental division of two nerves in

[1] A third cause, the relatively small number of heat spots, will be considered fully in a further communication by Dr. Rivers and one of us.

one of us, that these limits can be defined more accurately when the patient is a trained observer, capable of devoting the necessary time to examination. But for clinical work we have selected these limits to avoid the confusion introduced by the profound variations in sensibility due to external conditions which cannot be avoided in practice. Fatigue and cachexia cause the affected part of the hand to become blue and cold. When in this condition, it is much less sensitive to all forms of temperature stimulation, more particularly to heat and to the minor degrees of both heat and cold. Of all external influences producing this state, the weather is the most powerful. Extreme external cold will render the hand blue and insensitive; but the actual external temperature registered by the thermometer is not the sole factor in this change. What is usually called a "raw" day, misty, damp, and cold, is more destructive of sensibility than one of the same temperature, but bright and sunny.

A hand that has reached the end of the first stage of recovery, sensitive to prick and to the more extreme degrees of temperature, is influenced physically to a greater extent than normal parts when warmed and cooled. Placed in hot water the affected half becomes warmer than the normal parts of the palm. Conversely, when cooled with ice-water, the parts that have reached the end of the first stage of recovery may become colder than normal.

If the external temperature is low and the affected parts of the hand are blue, it may be necessary to lower the temperature of the test tube to 18° C. before parts that have recovered sensibility to prick react, and the patient appreciates the cold stimulus. In like manner even 50° C. may scarcely be appreciated as heat. Conversely on a warm summer day when the colour of the parts affected cannot be distinguished from that of the normal hand even 24° C. may be called cold and 40° C. hot. Such acuity of perception is rare even under the most favourable external conditions.

In such a case, supposing a patient can appreciate 24° C., there is no gap in his sensation at the cold end of the scale; for on the normal skin any temperature above this point is

usually said to be neutral, neither hot nor cold. But whether the highest point appreciated be 18° C. or 24° C., the sensation of cold, produced over parts which have become sensitive to prick but not to light touch, is profoundly abnormal. It is diffuse and radiates widely to a distance from the point stimulated. It may even seem colder than over normal parts, and in addition possesses a "tingling" quality which is very characteristic. By this we know that although sensation is produced over the full range usually associated with cold, yet that sensation is abnormal. It differs from that produced by 24° C. over normal parts in its diffuseness and wide radiation. Moreover, it shares these abnormal qualities with the sensation to cold present over the intermediate zone and over the hand which reacts to no cold stimulus higher than 18° C.

At the other end of the scale there is always an obvious loss of sensation, however perfect the external conditions may be. For 40° C. is the lowest warm stimulus to which any of our patients reacted over parts in the state under discussion. Yet on the normal skin 34° C. is frequently said to be warm, and 36° C. distinctly hot. Thus, in these cases sensation to heat is absent and not simply defective over a certain range of temperature, however favourable the external conditions. But here also, as with sensibility to cold, even if 40° C. can be appreciated, the sensation produced radiates widely from the point stimulated. It is "tingling" and diffuse.

In this condition the hand remains for a variable period, sensitive to prick and to the more extreme degrees of temperature, but insensitive to light touch and the intermediate grades of heat and cold. With the first signs of returning sensibility to light touch, temperatures of 22° C. and 38° C. begin to be appreciated with certainty as cool and warm. If the patient is intelligent he states that the radiation and diffusion, so intrusive over parts still in the earlier stage of recovery, is no longer noticeable.

Among fourteen cases, where one or more nerves to the hand had been completely divided, sensibility to light touch and to the intermediate degrees of temperature was restored

simultaneously in twelve. No. 18 (Table II. and fig. 1, A) became sensitive to warmth over the proximal parts of the affected area nearly three months before any response could be obtained to cotton-wool. But simultaneously with this reaction to warmth, he became sensitive to the interrupted current, produced without iron in the circuit, to which it had been previously insensitive. In one instance only (No. 3, Table I., fig. 3, E) was stimulation with cotton-wool appreciated before the restoration of sensibility to warmth, and in this case the interval between the return of the two forms of sensation was not more than one month.

The following are the results to which we have arrived in this section :—

(1) Immediately after a peripheral nerve has been divided, all sensibilty to heat and cold is lost over the area insensitive to prick. The intermediate zone between the borders of the loss of sensation to light touch and the area of total insensibility to prick remains sensitive to temperatures above 50° C. and below 18° C., but is insensitive to any temperature between about 22° C. and 40° C.

(2) Sensibility to the extremes of heat and cold usually returns step by step with that to prick. At last, a stage is reached on the road to recovery, when all the parts affected are sensitive to temperatures below 18° C. and above 50° C. But the sensation caused by these temperatures is of a different character from that they produce over the normal skin. It radiates widely and is accompanied by an abnormal tingling.

(3) After the hand has remained for a variable period in this condition of sensibility, the intermediate degrees of temperature between about 22° C. and 40° C. begin to be again appreciated. This return usually coincides with that of sensation to light touch, but may precede it by a short period under favourable conditions.

Chapter 10.—The Compass Test.

Discrimination of two points separated from one another for a varying distance is one of the oldest tests for sensation.

But it has fallen into disuse as a means of clinical investigation in consequence of the difficulties with which it is surrounded, and the incomprehensible results yielded by the test when carried out in the usual manner. To McDougall (9) we owe a modification which not only makes it easy to use the two points as a test for sensation even in hospital patients, but gives to the records a definiteness otherwise lacking. The blunt points of a pair of compasses are separated from one another for a measured distance. The skin of the affected part is touched, and the patient, whose eyes are covered, is asked to say after each application whether he was touched by one or two points. When they are separated for less than a certain distance, varying with the different parts of the body, the points no longer appear as two on the normal skin. Under the old method the patient was also touched a few times with one point as a test of his trustworthiness. But in all our observations the patient was touched ten times with one point and ten times with two points, each form of stimulation being applied entirely at random in the series. This modification of the original method adds considerably to the value of the compass test; for we now pay attention not only to the number of times two points are mistaken for one, but also lay stress upon the frequency with which stimulation with one point is said to be two. The results are recorded graphically in the following manner: Every time the patient's answer is correct a stroke is made, above a horizontal line if he was touched with one point, below it if he was touched with two points. An incorrect answer is recorded by a cross. Thus, if he answers "one" when touched with two points, a cross is placed below the line; if one point has been called two, the cross is drawn above the line. A preceding stimulus frequently has an effect upon those which follow it, and to register the order in which the stimuli have been applied is therefore an additional aid to the interpretation of the records. Thus, if the testing began with four double touches correctly answered, four strokes would be ranged below the line from left to right. At the point above the line directly over the last of these double touches would begin the record

of the subsequent single stimuli. In this way, the results of all further stimuli are recorded until the number is complete. As ten stimuli of each kind are used, the results can be reduced to percentages at once. For additional accuracy we use the letter "D" whenever the patient is in doubt, and "O" whenever he fails to answer at all.

Perfect appreciation of the compass points at a distance of 2 cm. would be represented thus :—

$$2\text{ cm. } \frac{1 \mid 111 \quad 11 \quad 11111}{2 \mid \quad 1111 \quad 111 \quad 111}$$

If, however, the patient is unable to differentiate the two points at this distance, answering "one" to every stimulation, the record would stand :—

$$2\text{ cm. } \frac{1 \mid \quad 1111 \quad 11 \quad 1111}{2 \mid XX \quad XXX \quad X \quad XXXX}$$

Such a formula would show that when 2 cm. apart, the sensation produced by two points is well below the threshold at which discrimination becomes possible. Less complete failure would be represented by some such formula as :—

$$2\text{ cm. } \frac{1 \mid \quad 11XX \quad 1X \quad 1XX1}{2 \mid X1X \quad 11XX \quad XX1}$$

where 50 per cent. of the answers are wrong with one point, 60 per cent. with two points. A curious phenomenon, upon which we shall lay considerable stress, is the tendency to appreciate one point as two over parts of defective sensibility as soon as the limits of accurate discrimination are passed.

In every case our observations were controlled by testing a similar part of the sound hand. We found that almost without exception two points could be accurately discriminated over any part of the normal palm when separated for 1 cm. and applied transversely.

The compasses may be applied either transversely or along the vertical axis of the limb. We have been content in most cases with a strictly transverse position which allows of accurate discrimination at a smaller distance than when the two points are placed in the axis of the limb. But where the area to be examined consists of a long and narrow strip upon the palm, we have also made use of the longitudinal position controlling our observations by an examination of a similar portion of the normal hand.

The conclusions detailed in this section are founded upon the results of 340 sittings, with fifty-eight patients, conducted according to the method we have just described.

Immediately after division of a nerve trunk, a part of the hand becomes totally insensitive. Over such parts, all sensation is abolished, and the compass test is, therefore, inapplicable. But the extent of loss to light touch usually exceeds considerably the analgesic area. This intermediate zone is frequently of sufficient size to make the compass test possible, especially when the loss of sensation has been produced by division of the median nerve. After division of this nerve, nine patients failed to distinguish the two points when they were separated for 2 cm., and three failed at a distance of 3 cm. This number would probably have been greater, had it been possible to apply the compasses at this distance more frequently. Limitation of the field to be examined compelled us to choose some distance such as 2 cm. obviously far above the threshold of sensibility of the normal skin; we then based our judgment on the gradual improvement shown by the formula obtained at this distance. Had the area at our disposal been larger, we should have depended rather on a gradual decrease of the distance between the points required for accurate discrimination. In every case where the median was known to have been severed, the patient gave more than 50 per cent. of mistaken answers when touched simultaneously with two points separated to a distance of 2 cm.

When the ulnar has been divided, the small extent of the intermediate zone makes it, in many cases, impossible to apply the test with the points at this distance. But in all five instances, where such a test was possible, owing to the relatively large extent of the intermediate zone, the patient totally failed to discriminate between the two points at 2 cm. In two instances we were able to use them 3 cm. apart and, even at this distance, the answers were uniformly wrong whenever the two points were applied simultaneously.

In consequence of the comparatively small area insensitive to prick, the extent of the palm suitable for this test becomes larger where the ulnar has been divided on the

distal side of its dorsal branch. Yet every patient, with this form of injury, failed to distinguish the points at 2 cm., and in one instance, where an unusual extent of the palm was affected, they could not be discriminated even when 4 cm. apart.

Return of sensibility to prick and to the more extreme degrees of heat and cold, in no way improves the power of distinguishing a pair of compass points. The whole of the affected parts of the hand may become sensitive to such stimuli, and the patient may experience more than usual discomfort when pricked; yet even when separated for 3 cm. he may entirely fail to perceive that he is touched by more than one point.

Over the intermediate zone it was only possible to use the points at a distance less than 2 cm. from one another. After the hand has become acutely sensitive to prick two points, at this distance applied to parts that had once formed the intermediate zone, yielded a formula in no way superior to that originally obtained. Evidently the return of this form of sensibility makes no difference to the acuity of the patient towards the compass test. It is frequently impossible to make use of the compasses until sensibility to prick has returned, in consequence of the smallness of the intermediate zone. Yet, although it may not have been possible to test the hand until it has become partly sensitive, the record of the compasses at 2 cm. is mostly so bad ($\frac{1 \mid 10 \text{ Right}}{2 \mid 10 \text{ Wrong}}$) that return of sensation to prick cannot have improved materially the power of distinguishing two points.

Nowhere can this be shown in a more striking manner than after division of the median and ulnar nerves; at first the palm may be totally insensitive, and compasses cannot be used. Gradually sensibility to prick returns, the whole palm becomes available for testing, and it is found that two points separated to a distance of 5 or even 6 cm. cannot be discriminated. Thus nine months after suture of the two nerves, Mrs. L. (Case 26, Table III.) was unable to distinguish two points at 5 cm. (5 cm. $\frac{1 \mid 10 \text{ R.}}{2 \mid 10 \text{ W.}}$); three months later the same parts gave a perfect formula at 1 cm. In the same way 70 per cent. of the answers made by B.

(Case 28, Table III.) at 6 cm., after the whole palm had become sensitive to prick were erroneous (6 cm. $\frac{1 \mid 10\ R.}{2 \mid 3\ R.\ 7\ W.}$). But six months later, with the points at one-third of this distance apart (2 cm.) an identical formula (2 cm. $\frac{1 \mid 10\ R.}{2 \mid 3\ R.\ 7\ W.}$) was registered over the same area.

Immediately light touch begins to be appreciated over the area affected the compass records respond to the change. At first, sensation becomes uncertain over parts in the neighbourhood of the wrist. A few weeks later light touch can be certainly appreciated over the proximal part of the distribution of the injured nerve, although the distal parts of the palm still remain insensitive. A hand in this condition reveals clearly the close connection between sensibility to light touch and the discrimination of the compass points; near the wrist seven out of ten answers may be right, while over more distal parts of the palm all ten may be incorrect.

Ultimately the whole of the hand becomes sensitive to light touch; but, although the formula shows marked improvement and the distance between the points can be greatly decreased, sensibility to this test still remains defective. This is the stage associated with a "line of change." A pin drawn lightly across the skin from normal to abnormal parts produces a changed sensation as soon as the boundary of the original loss of light touch is passed. The sensation produced becomes more uncomfortable and has a curious tingling which even patients of the meanest intelligence cannot mistake. So long as the hand is in this condition the discrimination of the compass points remains defective, and it would seem that the existence of this state depends on a defect in that form of sensibility which gives precision to the appreciation of two points.

At last sensation may be so completely re-established that the compasses reveal no material difference between the two hands. But so perfect a restoration requires several years, and long before it was reached most patients considered the hand was as good as ever. They ceased to come at our request, or failed to let us know a change of address. A few remained faithful to the end. Amongst them one case of divided ulnar (No. 18, Table II.) gave a perfect

formula at 1 cm. exactly two years after the accident, and a case of divided median (No. 4, Table I.) reached the same condition two years and nine months after suture of the nerve.

If anything has happened to retard recovery, if the wound has suppurated or the ends of the divided nerve have not been brought into apposition, compasses may reveal a permanent defect, although the hand has become sensitive to all forms of stimulation. We have seen an old man who accidentally divided his ulnar nerve in 1843. To all forms of touch, to prick and to temperature, sensation had returned. But over the whole distribution of the ulnar nerve sensation was changed, the pin point became sharper, and cotton-wool caused a tingling sensation; compasses were defective over the whole ulnar palm (1 cm. $\frac{1|9\,\text{R.}\,1\,\text{W.}}{2|3\,\text{R}\,7\,\text{W.}}$).

One of our students divided the median nerve of his right hand. When we saw him six years later he responded to all forms of stimulation, but his sensibility to compasses was comparatively low. On the palm of the sound hand he was accurate at 0·5 cm.; on the median area of the injured hand he failed with both one and two points at 1·5 cm. (1·5 cm. $\frac{1|6\,\text{R.}\,4\,\text{W.}}{2|3\,\text{R.}\,7\,\text{W.}}$). At the same time he showed an exquisite line of change. In fact, we can state with certainty, that so long as this line of change still remains, the compass points will show that sensation is still below the normal.

When a nerve trunk is injured, but not completely divided, the loss of sensation depends on the gravity of the injury. All forms of sensation may suffer so severely that to all appearances the nerve has been completely severed. But within a month or six weeks sensation to prick may begin to return, and with it the extent of the anæsthesia to light touch and to minor degrees of heat and cold diminishes. This simultaneous return of the two forms of sensibility is a certain indication that the nerve has not been severed, however grave the injury may have been. It is, therefore, of extreme importance to determine with certainty whether sensibility to light touch is returning or not. Cotton-wool is often an untrustworthy stimulus. But the compass points show at once if the loss to light touch has begun to

diminish in intensity or extent. For it has been shown that return of sensibility to prick in no way improves the power to appreciate two points; any coincident improvement in sensation shown by the compass test must, therefore, signify a simultaneous improvement in forms of sensibility other than those grouped around sensation to prick. As a matter of fact it will be found, that whenever the compass records show considerable improvement, the parts which have so improved have become sensitive to minor degrees of heat.

Case 29, Table IV., p. 164,[1] is an excellent instance of this condition. A young man cut his wrist whilst loading some bottles upon a van. The loss of sensation produced by the injury corresponded to that which would follow complete division of the median nerve; even the palm was in part insensitive to prick and to the extremes of heat and cold. But exploration of the wound by one of us showed that the nerve was injured without destruction of its continuity. Within a month of the injury sensibility to prick had improved greatly; at the same time we suspected that the parts in the neighbourhood of the thenar eminence were sensitive to cotton-wool. This suspicion was confirmed by the character of the records yielded by the compasses from the palm in the neighbourhood of the thumb and at the base of the index and middle fingers.

Palm at base of thumb, 1 cm. $\frac{1 \mid 9\text{ R. }1\text{ W.}}{2 \mid 4\text{ R. }6\text{ W.}}$

Palm at base of fingers, 1 cm. $\frac{1 \mid 3\text{ R. }7\text{ W.}}{2 \mid 4\text{ R. }6\text{ W.}}$

It will be seen that, although the same number of wrong answers were given in both places with two points, the single point was rightly appreciated nine times out of ten over a part where sensation to touch had more distinctly returned, whilst three only out of ten answers were correct over the remainder of the palm. This was no fortuitous difference, for in a month's time the compasses were perfect at 1 cm. over the neighbourhood of the thumb, though still defective over the remainder of the palm (1 cm. $\frac{1 \mid 5\text{ R. }5\text{ W.}}{2 \mid 9\text{ R. }1\text{ W.}}$).

Not infrequently, the pressure of a tight bandage or badly adjusted splint causes a diminution of sensibility to light touch amounting even to complete insensibility to cotton-wool. Such loss is accompanied by a profound

[1] *Vide* Appendix, p. 302.

alteration in the power of appreciating two points, and even if light touch, tested with cotton-wool, is present, the compasses reveal the diminution in sensibility with unmistakable distinctness.

Case 61.—*Diminution in sensibility to cotton-wool and to the compass test, produced by pressure on the ulnar nerve at the elbow.*

A youth, who was thought to have fractured his clavicle, was strapped by Sayre's method. The little finger became painful during the time the strapping was in position, and later the ulnar half of the hand became numb. When we saw him three months after the accident the muscles of the hand were acting, and contracted normally to the interrupted and to the constant current. Over the whole ulnar area sensation was lowered to cotton-wool, and over the parts where light touch was diminished a prick produced a more intense and diffuse pain than over the normal hand. Water at 25° C. and at 35° C. were everywhere appreciated. At a distance of 1 cm. two points were not discriminated eight times out of ten (1 cm. $\frac{1|8\,\mathrm{R.}\,2\,\mathrm{W.}}{2|2\,\mathrm{R.}\,8\,\mathrm{W.}}$). Yet two months later light touch had everywhere returned and the record of the compasses at 1 cm. was perfect.

By means of the compasses it is possible to obtain information concerning the relative sensibility of parts which react to all the coarser tests. If the hand is sensitive to all grades of temperature that can be used in practice, and if cotton-wool is appreciated over the whole extent supplied by the injured nerve, it would be impossible without the aid of the compasses to say that one part of this area was more advanced towards recovery than another. But the record of the two points will show that the proximal portion of the palm is more sensitive than that nearer the base of the fingers.

The following case (No. 34, Table V., p. 168[1]) is a good example of the manner in which improvement of sensation can be measured after the hand has become sensitive to all the ordinary stimuli.

A man of 48 years of age cut his left wrist on March 4, 1903. Under an anæsthetic the wound was explored, and several

[1] *Vide* Appendix, p. 312.

divided tendons were sutured; the ulnar nerve was found to be injured, but not completely divided below the point at which the dorsal branch was given off. This injury caused loss of sensibility to prick over the palmar aspect of the little finger, and anæsthesia to light touch over the ulnar half of the ring finger, the palmar aspect of the little finger and the whole ulnar palm. Over this area intermediate degrees of temperature were not appreciated. The interosseous muscles of the second, third and fourth spaces, and the abductor minimi digiti, were inactive and ceased to respond to the interrupted current. Rapid improvement took place; sensibility to prick began to return, followed quickly by that to light touch. By August 26, 1903, twenty-five weeks after the accident, the hand had become sensitive to all forms of stimulation; but light touch was badly appreciated, and the compasses gave a defective record at 2 cm. The affected parts improved, until just a year after the accident (February 28, 1904) all parts of the palm appeared to be equally sensitive to all forms of stimulation. But over that part nearer to the wrist the compass points gave a record at 1 cm., which showed that the threshold had been approached (1 cm. $\frac{1 \mid 5\text{ R.}, 5\text{ W.}}{2 \mid 6\text{ R.}, 4\text{ W.}}$). Nearer to the base of the fingers the two points were wrongly appreciated in every instance (1 cm. $\frac{1 \mid 10\text{ R.}}{2 \mid 10\text{ W.}}$). This difference proved that sensibility was steadily returning from the more central to the more peripheral parts of the affected area. On September 25, 1904, eighteen months after the injury, sensation was still changed over the ulnar area; the point of a pin caused more discomfort, and this increased reaction began at the old line of anæsthesia to light touch. Over the proximal parts of the palm at 1 cm. the compasses yielded a somewhat improved record (1 cm. $\frac{1 \mid 10\text{ R.}}{2 \mid 7\text{ R.}, 3\text{ W.}}$). More distal portions still showed ten false answers with the two points (1 cm. $\frac{1 \mid 10\text{ R.}}{2 \mid 10\text{ W.}}$).

All the higher forms of sensibility are peculiarly susceptible to the influence of bodily states. We have dwelt upon the way in which recovery may appear to be arrested in consequence of cold or unpropitious weather. But the records yielded by compasses are also influenced by other conditions, such as mental fatigue and particularly alcohol.

By the method we have adopted, an erroneous appreciation of one point is registered equally with the misapprehension of two. And among the formulæ cited to support our contentions in this chapter, the reader will have been

struck with the frequency of mistakes in the upper row of symbols. By most clinical observers such errors are supposed to show that the patient is untrustworthy; but experimental psychologists have long recognised that this doubling of a single stimulus is a phenomenon closely associated with an approach to the threshold of sensation. If the compasses are separated for a distance too small for just appreciation, every stimulus, whether by one or two points, is frankly called one. But, if the distance is increased, some stimuli with two points will be called "one," some with one will be called "two." Occasionally every touch with a single point appears to be double, although every touch with two points is correctly appreciated. Such a complete reversal never occurs in our experience with hospital patients, except over parts where the sensibility has been lowered by a definite nerve injury. For however careless, stupid, or alcoholic may have been the subject of our examination, we never observed an unbroken series of doubled single touches amongst the control tests we always applied to the uninjured hand.

Case 5 (Table I. and fig. 3, L.).—*Gradual recovery of sensibility to the compass test after suture of the median nerve.*

On October 2, 1902, a butcher cut his wrist with a knife. Two days later sensation was lost over the area shown in fig. 3, L. The space between the border of the loss to prick and that to light touch was sufficient to permit of the compass points being applied at a distance of 2 cm. apart, and the records were as follows:—

October 4, 1902, 2 cm. $\frac{1 \mid 10\text{ R.}}{2 \mid 4\text{ R. }6\text{ W.}}$, 1 cm. $\frac{1 \mid 10\text{ R.}}{2 \mid 10\text{ W.}}$.

At the operation on October 4 the median nerve was sutured, and sensibility to prick began to return in the usual way. Thirty-three weeks later (May 24, 1903) light touch appeared to be lost over the whole median area, but the compasses showed slight improvement over the palm.

May 24, 1903, 2 cm. $\frac{1 \mid 7\text{ R. }3\text{ W.}}{2 \mid 10\text{ R.}}$, 1 cm. $\frac{1 \mid 6\text{ R. }4\text{ W.}}{2 \mid 8\text{ R. }2\text{ W.}}$.

By September 23, 1903, light touch was no longer lost over the palm, and the compass records showed material improvement.

September 27, 1903, 2 cm. $\frac{1 \mid 9\text{ R. }1\text{ W.}}{2 \mid 9\text{ R. }1\text{ W.}}$, 1 cm. $\frac{1 \mid 4\text{ R. }6\text{ W.}}{2 \mid 10\text{ R.}}$.

On November 25, 1903, all forms of sensation were

appreciated, but a well-defined change occurred at a line corresponding to the border of the previous anæsthesia to light touch. The compasses showed still further improvement in that the record at 2 cm. was now perfect (2 cm. $\frac{1 \mid 10\ R.}{2 \mid 10\ R.}$). At a distance of 1 cm. every stimulation with a single point was called "two," the phenomenon of "double ones" in a perfect form.

	Oct. 4.	May 24.	Sept. 27.	Nov. 25.
2 cm.	$\frac{1 \mid 10\ R.}{2 \mid 4\ R.\ 6\ W.}$	$\frac{1 \mid 7\ R.\ 3\ W.}{2 \mid 10\ R.}$	$\frac{1 \mid 9\ R.\ 1\ W.}{2 \mid 9\ R.\ 1\ W.}$	$\frac{1 \mid 10\ R.}{2 \mid 10\ R.}$
1 cm.	$\frac{1 \mid 10\ R.}{2 \mid 10\ W.}$	$\frac{1 \mid 6\ R.\ 4\ W.}{2 \mid 8\ R.\ 2\ W.}$	$\frac{1 \mid 4\ R.\ 6\ W.}{2 \mid 10\ R.}$	$\frac{1 \mid 10\ W.}{2 \mid 10\ R.}$

The above table shows clearly that recovery of sensibility is accompanied, not only by an increased appreciation of two points, but also by a simultaneous uncertainty in the sensation produced by single stimuli. At any one distance, such as 2 cm., the power of discrimination gradually increases until at last the record of both one and two points may become free from error.

But, in the above instance, when the points were 1 cm. apart every single stimulus was thought to be double, though every double stimulation was rightly appreciated. The serial arrangement of the records at this distance shows the gradual evolution of this phenomenon.

Chapter 11.—Sensibility of the Hairs.

Whilst watching the recovery of sensation after division of the ulnar nerve in one of our patients of unusual intelligence, we were astonished at the rapidity with which the back of the hand became sensitive to cotton-wool. We imagined that this was an individual peculiarity, until he gave us the clue, that led us back to a reconsideration of the sensibility of the hairs. When we stimulated with cotton-wool that part of the dorsal surface of the hand supplied by the ulnar nerve, he told us that the sensation radiated widely over the parts affected, and possessed a tingling character foreign to the sensation produced by stimulating normal parts of the hand. Now radiation and a tingling quality had come to be associated in our minds with that form of sensibility which returns early to the

affected hand; pain, cold and heat, in as far as they are appreciated by a hand in the first stage of recovery, all produce sensation with this peculiarity. It seemed, then, that on the dorsal surface of the hand some structure had become sensitive to cotton-wool at about the time when sensibility to prick was fully established. Such a structure is to be found in the hairs which are never absent from the back of the hand of men, and are present even on the hands of most women.

Case 15 (*vide* Table II., p. 156, and fig. 1, G, p. 127).—*Complete division of the ulnar nerve at the point where its dorsal branch is given off. Presence of sensation to cotton-wool due to the innervation of the hairs before the return to the hairless skin of sensibility to light touch.*

A lighterman, aged 29, was admitted to the Poplar Hospital on July 29, 1903, with a cut across his left wrist. He had lost sensation over the full ulnar area shown in fig. 1, G, p. 127. The wound was explored and the ulnar nerve was seen to be divided at the point where it gave off its dorsal branch. The upper end, a single trunk, was sutured to the two branches which constituted the peripheral portion of the nerve. All the muscles in the hand supplied by the ulnar nerve were completely paralysed and ultimately lost their reaction to the interrupted current. The wound suppurated and did not heal for seven weeks.

On December 2, 1903, sensibility to prick and to ice had returned over the palm, but was absent over the same area as before on the dorsal surface of the hand, which did not become sensitive to these stimuli until March 23, 1904 (237 days after suture).

By June 12, 1904 (320 days after suture), the whole of the dorsal surface of the hand not only reacted to prick and to ice, but had become sensitive to stimulation with cotton-wool. But when that part of the hand supplied by the dorsal branch of the ulnar nerve was shaved, it became at once entirely insensitive to any form of light touch. This experiment was repeated many times under varying conditions, for it was not until April 9, 1905 (619 days after suture), that this portion of the hand became sensitive to cotton-wool when shaved.

From the beginning, this patient recognised that the sensation caused by cotton-wool over the normal parts of the back of the

hand was different from that over the affected area. He said: "When you touch the back of my hand (over the ulnar border) it is a kind of crawling, prickly feeling." Later, he learnt to associate this peculiar sensation so definitely with hairs, that he could tell us if after shaving we had left any still standing above the surface. This explanation received additional support from the fact that sensibility to warmth (below 40° C.) and to the painless interrupted current was absent over the area on the dorsal surface of the hand, which exhibited this radiating and abnormal sensibility to cotton-wool.

A similar condition appeared in one of us during the recovery of the radial half of the back of the hand after experimental division of the radial (ramus superficialis nervi radialis) and external cutaneous nerves in the neighbourhood of the elbow. Within eight months of the operation, this part of the back of the hand had become sensitive to prick, to ice, and to water at 50° C. With this return of sensibility, the hairs began to react to cotton-wool, and this stimulus evoked a curious radiating sensation with a characteristic tingling quality. True localisation was impossible, and the skin over the same parts became, when shaved, entirely insensitive to cotton-wool.[1]

In both these instances recovery was considerably delayed. The wound in the first suppurated badly; in the second case the nerves had been divided at the elbow, and the period between the return of sensibility to prick and that of the recovery of light touch was consequently longer than usual. This return to the hairs of a peculiar form of sensibility characterised by wide radiation seems to occur when the sensation to prick, to ice, and to water at 50° C. has been present alone over the affected parts sufficiently long to be fully restored.

It would seem, then, that return of sensibility to prick and to the more extreme degrees of heat and cold brings a return of sensation to the hairs on the back of the hand. They then react not with that well-localised sensation we are accustomed to associate with stimulation of hairs, but

[1] This case will be dealt with more fully by Dr. Rivers and one of us in a subsequent number of this Journal.

with a wide-spread tingling, analogous to the radiating sensation produced by a prick or by cold water at the same stage of recovery.

Sensibility is gradually restored, and the back of the hand becomes sensitive to cotton-wool even when shaved. As sensation becomes more perfect the tingling quality disappears, the stimulus can be localised correctly, and the hairs regain their normal sensibility.

We have shown that, under certain conditions, the hairs may regain a peculiar form of sensibility at the time when the affected parts are sensitive only to prick and to the extremes of heat and cold.

Plucking a normal hair will, in most cases, cause pain, and it is this sensibility to pain that returns to the hairs when they react in this manner to stimulation with cotton-wool.

But it is obvious that stimulation of normal hairs produces a well-defined and well-localised sensation differing entirely from the radiation and tingling so characteristic of all sensation at the close of the first stage of recovery. The hairs must, therefore, be endowed with some additional innervation other than that which may be restored with the return of sensibility to prick.

If it were possible to examine a part sensitive to light touch only, the significance of this innervation would become manifest. We have fortunately been able to examine five cases where sensibility to cotton-wool was present over parts insensitive to prick and to the extremes of heat and cold. Here the hairs were in a sensory condition, complementary to that described in the first part of this chapter.

The first instance (Case 85)[1] of this remarkable condition occurred in a plumber who divided the median together with the radial and part of the external cutaneous nerve in the neighbourhood of the wrist. Over the back of the hand in the region of the first interosseous space was a small area entirely insensitive to prick and to the extremes of heat and cold. But over this patch of skin he was

[1] *Vide* Appendix, p. 328.

sensitive to stimulation with cotton-wool, or to any other stimulus which affected the hairs. Here he also correctly appreciated the difference between water at 25° C. and 38° C.

This was almost exactly the condition of the triangular patch of dissociated sensation which appeared in one of us after experimental division of the radial (ramus superficialis nervi radialis) and external cutaneous nerves at the elbow.

This power of appreciating the movement of hairs, and of localising the point at which the stimulus is applied, can be present although the skin is insensitive to all forms of temperature, and even when, after shaving, it becomes entirely anæsthetic, as shown by the following instance.

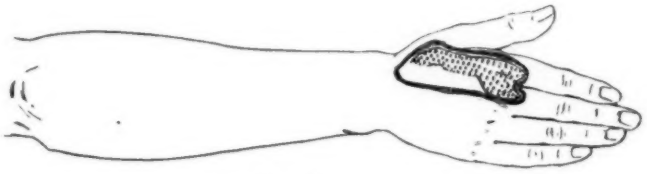


FIG. 27.

To show the extent of the loss of sensation produced by division of the internal branch of the radial and posterior branch of the external cutaneous nerves in Case 62.

The dotted area was insensitive to all forms of cutaneous stimulation. Within the area enclosed by a thick black line the hairs were sensitive, but all sensation of pain, heat, and cold, was absent.

Case 62.—*Division of the internal branch of the radial nerve (ramus dorsalis nervi radialis superficialis), with the posterior branch of the external cutaneous at the wrist, producing an area of dissociated sensibility.*

W. C., aged 21, cut his right wrist with glass on May 18, 1905. The same evening the internal branch of the radial nerve and the tendon of the supinator longus were sutured.

On May 24 we found that he was insensitive to prick over the radial half of the dorsum of the hand (fig. 27.) Sensation was unaltered over the thumb and fingers. The whole of this area was insensitive to all degrees of temperature, but he responded briskly to pressure or any form of deep touch.

Stimulation with cotton-wool was not appreciated over a considerable portion of this area. But over a strip towards its ulnar side, about 4·5 cm. in length and from 1·2 to 1·5 cm. in breadth, cotton-wool produced a tickling sensation. Over the normal parts plucking a hair caused him to say that he was being pricked; but within the area of dissociated sensation he said: "You are touching me, you tickle me." Over the area insensitive to all cutaneous stimuli but sensitive to deep touch, he failed entirely to appreciate a pull sufficiently severe to lead to the removal of the hair.

The sensation produced by cotton-wool within this area of dissociated sensibility was a well-localised tickling, entirely different from the radiating tingling sensation described in the first half of this chapter.

He failed in every case to discriminate two points of the compasses at 4 cm., applied longitudinally over this area; over a similar part of the sound hand the test gave a perfect result at 2·5 cm.

After completing these observations the back of the hand was shaved. The whole of the parts insensitive to prick and to temperature were then found to be entirely anæsthetic to cotton-wool, proving that the sensibility previously existing must have been due to the hairs. Over normal parts of the back of the hand when shaved cotton-wool could be accurately appreciated.

Thus, in conclusion, we believe that the hairs receive a double innervation. When all cutaneous nerves are divided and deep sensibility alone remains a hair can be plucked out without producing any sensation. But as soon as the hand has become fully sensitive to prick and to the extremes of heat and cold, pulling the hairs produces pain, and stimulation with cotton-wool evokes a peculiar radiating, tingling sensation. Later, when the hand has regained sensibility to light touch, this tingling quality disappears, giving place to the well-localised sensation produced when normal hairs are gently moved.

Should the part be sensitive to light touch, though insensitive to prick, movement of the hairs will produce a well-localised tickling sensation. But a hair can be plucked out without producing more than a sensation of touch.

Chapter 12.—Hyperalgesia.

A hand that has passed through the first stage of recovery has become sensitive to prick. So great is the discomfort, and so brisk the movement of withdrawal, when the hand is pricked, that the parts affected are not infrequently said to be "hyperæsthetic" (or more accurately "hyperalgesic"). We have shown that excessive reaction to this form of stimulation is associated with loss of all the finer forms of sensation; it is due to the presence of a

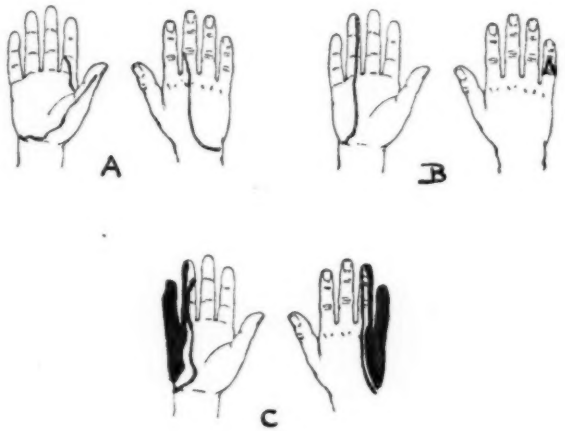


Fig. 28.

A shows the extent of the hyperalgesia produced by irritation of the ulnar nerve in Case 63.
B shows the extent of the loss of sensation to light touch present before the operation.
C shows the loss of sensation produced by dividing the ulnar nerve in the same patient.

peculiar form of sensibility. It is, in fact, the expression of a deficiency rather than of excess, and it disappears gradually with the return of the higher forms of sensation.

But a true exaggeration of sensibility to pain may exist apart from any defect in sensation of light touch. Such hyperalgesia is rarely the result of wounds of peripheral

nerves in modern surgical practice, but it underlies the remarkable condition described by Weir-Mitchell (14) under the name of "causalgia" and can still be seen as he described it after injuries particularly with the older forms of bullets. G. H. (Case 63)[1] showed this sensitiveness in so typical a form that a description of his condition might have been taken from the pages of Weir-Mitchell.

He was wounded at Tweefontein on July 22, 1901, by a bullet that entered 4½ ins. (11·5 cm.) below the internal condyle of the humerus, passing across the forearm to the radial side. Not until he had been in hospital three weeks did the hand become painful. The pain became steadily more intense, and when we saw him first (January 26, 1902) was constant. At that time, the skin of the hand was characteristically smooth, glossy and of a pinkish-blue colour, the fingers tapered and the nails were long and curved.

The hand was intensely tender over a large area, occupying the palm, the ulnar half of the thenar eminence, the palmar aspect of the thumb and the palmar aspect of the little, ring and middle fingers. Over the dorsal surface this tenderness occupied the ulnar half of the hand and extended to the tendon of the ring finger. The skin of the dorsal surface of the little, ring and middle fingers was intensely sensitive to pinching, to pressure with the head of a pin and to the pin-point.

Sensation to light touch and to the painless interrupted current was lost over the usual ulnar area, and here the discrimination of the compass points was extremely defective. Sensibility to the more extreme degrees of temperature was perfect everywhere, but ice and water at 50° C. tended to cause pain.

This man's hand, as far as the loss of sensation was concerned, was exactly in the condition which follows an injury without complete destruction of the ulnar nerve. Hitherto in all our cases excessive sensibility to prick has been confined to the so-called anatomical distribution of the

[1] *Vide* Appendix, p. 316.

affected nerve; that is to say, over-sensitiveness to prick so far has always coincided with the limits of loss to the higher forms of sensation. When the ulnar nerve was destroyed it lay within an area on the palm to the ulnar side of a line through the axis of the ring finger.

But here the tenderness exceeded the area of loss of sensation caused by injury to the nerve, extending on to the median half of the palm. Moreover, it was found over parts that were in no way insensitive to light touch, the interrupted current, or the two points of the compasses.

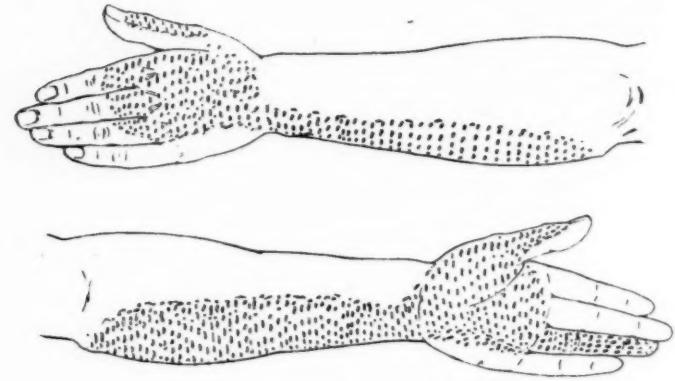
Obviously this wide extent of hyperalgesia might be explained by supposing that the median nerve had also been affected by the injury. But, apart from the total absence of motor or sensory paralysis pointing to injury of this nerve, this explanation was at once negatived by the results that followed division of the ulnar. On the afternoon of January 30, the ulnar nerve was separated from fibrous tissue, the two ends freshened, and then united by means of a graft. Next morning all pain and tenderness had gone from the hand, and the sensation of the ulnar half was such as might have been expected after total division of the ulnar nerve.

It is therefore certain that the impulses, which produced the true hyperalgesia over the median half of the palm, must have travelled by way of the ulnar nerve. The pain must have been caused by some irritation of the trunk of this nerve; and yet the tenderness far exceeded any area of loss of sensation produced by division of the ulnar nerve.

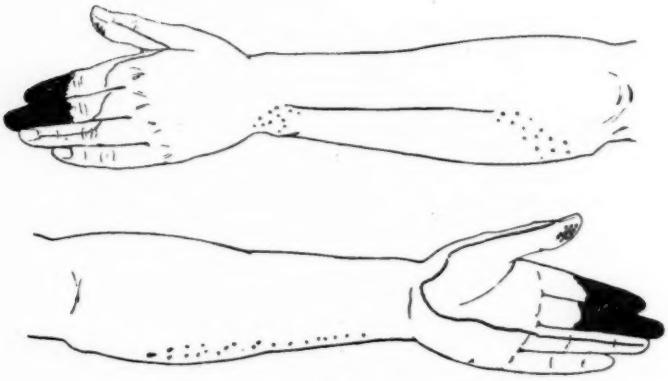
The following case illustrates a similar hyperalgesia produced by injury of the median. The absence of any exploratory operation and our consequent ignorance of the limits of the loss of sensation that would have been caused by division of the nerve affected make it less convincing; but, in the light of the previous observation, the condition would appear to have been caused by injury of the nerve combined with irritation of its trunk.

J. W. (Case 64),[1] an Imperial Yeoman, was shot through the arm with a Martini bullet on August 1, 1901. The Boers

[1] *Vide* Appendix, p. 332.



A



B

FIG. 29

A, to show the area which became intensely tender in Case 64.
B, to show the extent of the loss of sensation in the same case. Total cutaneous insensibility is shown in black. The area of loss of the higher forms of sensation (light touch, &c.) is enclosed in a single line.

took from him all they wanted, and he lay for two days and one night on the veldt. He was then found and taken to hospital. The wound "became very foul," and did not heal for more than five weeks. At first the arm was painless, but about a month after he was wounded, pain began in the hand and steadily increased. After a while the pain was always present and of about the same intensity, except when the weather was cold. In the winter it was scarcely troublesome so long as the hand was exposed to the cold and cold water always removed the pain for a time.

The bullet had entered the left arm at a point $1\frac{1}{2}$ ins. (4 cm.) above the external condyle of the humerus; $2\frac{3}{4}$ ins. (7 cm.) above the internal condyle lay the wound of exit, oval in shape and 1 in. (2·5 cm.) in its longest diameter. Both scars showed a tendency to become keloid.

This case was complicated from both motor and sensory aspects by injury to the musculo-spiral nerve. But for the purposes of the present chapter, it will be well to concentrate our attention on the sensory condition of the palm. Injury to the median nerve had produced loss of sensation exactly corresponding to that usually found, when the loss to prick has cleared away from the palm. Light touch and the minor degrees of heat and cold were lost over an area occupying the radial half of the palm, the index, middle, and half the ring fingers. The palmar aspect of the index and middle fingers and of the thumb were insensitive to prick and to the extremes of heat and cold.

At the same time, the opponens and abductor pollicis muscles were paralysed, wasted and inactive to the interrupted current.

This loss both of motion and sensation pointed to an injury amounting to functional interruption of the trunk of the median nerve. But in addition to these paralytic symptoms, J. W. complained of intense tenderness in the palm of the hand. The elbow supported by a sling, he walked about with his hand exposed, terrified lest it should be touched or jarred. The extent of this tenderness could be marked out by pressure with the head of a pin or by dragging the point lightly across the skin from normal to

abnormal parts. Comparison of the two figures (fig. 29, A and B) shows that the distribution of the tenderness considerably exceeded the area insensitive to light touch, extending to the ulnar side of the palm and occupying the whole of the ring finger. To the radial side it transgressed the line of anæsthesia to light touch on the thenar eminence and occupied the skin over the dorsal surface of the terminal phalanx of the thumb. The suffering caused, when the skin of the tender area was touched, exceeded anything we have seen in parts that have become over-sensitive to pain as a result of destruction of the higher forms of sensibility.

Thus we must conclude that this man suffered from an injury which interfered with both sensory and motor functions of the median nerve, and at the same time produced an irritative state manifested by tenderness of the palm of the hand of unusually wide distribution. This true hyperalgesia was absent over those parts of the hand which were totally analgesic, and did not invade the little finger or extreme ulnar border of the hand which, as we have seen, become totally analgesic when the ulnar nerve is divided.

In both the examples already given, the hyperalgesia was accompanied by some loss of sensation over the area supplied by the injured nerve. But in the following instance injury to the anterior division of the external cutaneous caused true hyperalgesia uncomplicated by any loss, even of the higher forms of sensation.

L. E. [Case 45, *vide* p. 180] fell on to a china jug, injuring the anterior division of the external cutaneous in the lower third of the forearm. Two weeks later he complained of pain, and the wound was reopened. When we examined him first, fourteen weeks after the accident, he was complaining of pain over an area extending from the position of the scar to the ball of the thumb.

Over the outer aspect of the forearm below the scar was an area, extending on to the thenar eminence, exquisitely tender to any form of pressure or to the point of a pin. Here sensation to cotton-wool was perfect, and

two points could be discriminated at a distance of 3 cm. when applied in the longitudinal axis of the limb. To this test there was no material difference between the two forearms.

From these examples it would seem that true hyperalgesia may make its appearance. But it is of rare occurrence and never arises immediately after injury.

It may co-exist with a variable amount of diminution in the sensory functions of the nerve, but disappears if the nerve is divided. It tends to return unless the injured portion is excised and the two ends sutured together. Simple division of the nerve does not suffice to effect a permanent cure.

The area occupied by this hyperalgesia extends to the remotest ramifications of the injured nerve as discovered by anatomical dissection and transcends on all sides the limits of even the most extensive loss of sensation produced when the same nerve is divided. When it occupies parts that are sensitive to light touch, its presence does not disturb the normal distance at which two compass points can be distinguished.

Chapter 13.—Changes in the Skin Associated with Nerve Injuries.

It is a matter of universal experience, that parts within the territory of an injured nerve are liable to undergo changes in the rate and nature of their growth. The nails may grow with unusual rapidity, and the skin become thin and glossy; or the epithelium remains heaped up into masses, and the growth of the nails may be scarcely perceptible. The parts may ulcerate, and painless whitlows be produced, in consequence of trivial injuries. Blisters arise without a burn or other assignable cause.

Such changes fall naturally into two groups, those associated with absence of sensibility to pain, and those that occur in parts that are hyperalgesic and the seat of spontaneous pain. Of these we shall first consider disturbances

of nutrition in parts insensitive to pain, not only because they more commonly follow the nerve wounds of civil life, but because they yield data required for a complete understanding of the trophic changes which accompany hyperalgesia.

When one of the nerves of the palm is completely divided the skin no longer desquamates so readily over the area of complete analgesia. This is particularly obvious when the patient happens to be a man who works with his hands. Normal parts of his horny palm protected by the cotton-wool of the dressings tend to become softer with disuse, but over the abnormal area the epithelium is not shed, remaining for many weeks as a rough layer on the surface.

When the wound is healed, and the splint removed from the hand, this want of desquamation is still visible in patients of the hospital class. But, if the hand is well scrubbed with soap and warm water, the dry epithelium comes away in flakes, exposing skin over the affected area, pinkish-blue in colour, colder than normal to the touch. This skin is inelastic and wrinkled, and the normal whorled markings are intersected by innumerable fine lines.

Over the back of the hand, these changes are even better seen than over the palm. Division of the radial and external cutaneous nerves[1] caused the skin of the radial half of the back of the hand to become inelastic; it somewhat resembled the skin of an old man. But in addition to this senile appearance, the superficial layers of the epithelium had formed scales; the affected parts were evidently drier than the normal skin, and the cracks better marked. This gave to the radial half of the hand an appearance resembling the skin of a toad. These changes corresponded exactly with the area insensitive to prick, to heat and to cold. The hairs were very irregular and did not lie in sweeping masses; they stood up or were laid in an uneven manner, each hair occupying a different position, as on an uncombed head. The whole of this area was of a slightly deeper red than

[1] The case of H. H., to be reported in full in a subsequent paper with Dr. Rivers.

the rest of the skin of the hand, and so definite was the difference in colour that it became impressed on the photographic plate as a well-defined patch darker than the surrounding skin.

In this condition the whole of the area insensitive to prick does not sweat. This causes a dryness which adds greatly to the scaly appearance of the affected part. If a pin is dragged lightly from normal to abnormal parts, it produces over the healthy skin a fine red mark which disappears rapidly, but over parts insensitive to prick, the point produces a white powdery line that lasts for many hours, or even days. This is best seen over the forearm or back of the hand, and is evidently due to the removal of dry epithelial scales.

A prick over an area in this condition draws blood easily, and the marks caused by this stimulation last for many hours after they have faded from the normal skin.

All these abnormalities disappear with the return of sensibility to prick. The hand or other affected part begins again to sweat, and may become moister than the surrounding skin. On the arm and leg, when sensibility to prick has returned, the skin no longer shows any distinctive peculiarity. But over the hand it becomes of a pinkish colour, and the rough hand of a man may gain an almost feminine fineness.

As soon as the hand becomes sensitive to prick, the original sensation of stiffness disappears and is replaced by soreness. It no longer seems to be encased in a tight glove, or to be painted with a layer of collodion; movement now causes pain, as if a bruised part were disturbed.

During the time when the skin is insensitive to pain it is peculiarly liable to injury; a burn or a cut is unperceived and it is therefore neglected. In this way sores and ulcers are produced, which from their situation or from the nature of the infection may lead to the destruction of a considerable portion of the finger. One of our patients, a stonemason, refusing to trouble about a painless ulcer, ground away the terminal phalanx of his finger against the stone he was occupied in sawing. If protected from

TABLE VII.—TROPHIC DISTURBANCES OF THE SKIN

No	Nature of Injury	Nerve United	Nature of Trophic Disturbance
Case 65	Ulnar. Glass cut. Primary suture. Suppurated	Dec. 27, 1898	Blister on ulnar side of palm .. ..
Case 19	Ulnar. Nerve divided and resutured	June 17, 1904	Whole of little finger red and shiny. Large blister
Case 15	Ulnar. Primary suture ..	July 29, 1903	Ulnar side of little finger, ulcer covered with scab
Case 18	Ulnar. Glass cut. Sutured fourteen days later	July 31, 1902	Dec. 3, 1902.—Sore on dorsum of first phalanx little finger
Case 30	Median incomplete. Glass cut	July 31, 1904	Oct. 7.—Small blister on tip of middle finger. Oct. 22.—Irritated to a large sore
Case 29	Median, incomplete. Glass cut, Sept. 20, 1902	Explored same day	Nov. 26.—Blisters on index and middle fingers ..
Case 31	Median, incomplete. Dec. 18, 1904. Glass cut	.. ..	Feb. 15, 1905.—Blister on index .. .. ..
Case 13	Median. Secondary suture	Feb. 6, 1905	Feb. 22.—Blisters between index and middle and middle and ring fingers
Case 12	Median. Secondary suture	Feb. 22, 1904	June 8.—Blister on palmar surface of terminal phalanx middle finger
Case 6	Median. Razor cut. Primary suture In consequence of a stitch abscess sensation became lost again	Oct. 3, 1903	Jan. 10, 1904.—Blisters on tip of index and middle fingers Oct. 26, 1904.—Oval ulcer, came as a blister in night on terminal phalanx middle finger. Dec. 22, 1904.—Large blister over index
Case 7	Median. Glass cut. Suture eight days later	Sept. 14, 1902	Nov. 26, 1902.—Blister on index. Second "blood blister" on same site a few days later
Case 66	Median, incomplete. Glass cut, Aug., 1901	.. ..	Nov. 4, 1901.—Tips of index and middle fingers bulbous. Both nails gone; nail-beds granulating surfaces
Case 5	Median. Knife cut. Operation two days later	Oct. 4, 1902	Dec. 10, 1902.—Ulcer and blisters index. Dec. 30.—Many fresh ulcers. March 8, 1903.—Black blisters on tip of index
Case 8	Median. Wrist cut with a piece of coal, Feb. 7, 1903	Feb. 9, 1903	March 4, 1903.—Two ulcers and a blister on index. Blister on palmar surface of middle finger. May 13.—Whole terminal phalanx of middle finger an open sore. Nail gone
Case 85	Median with radial and part of external cutaneous. Glass cut, April, 29, 1902. Secondary suture	June 3, 1902	Aug. 14.—Many ulcers and blisters on thumb, index and middle fingers. Sores continued to appear and tip of index became disorganised

FOLLOWING DIVISION OF THE NERVES OF THE HAND.

Cause Assigned	Result	Condition of Sensation at Time of Appearance of Tropic Change
Burn	Healed well	Protopathic loss over little finger and ulnar border of hand.
None	Healed in one month	Protopathic loss over little finger and ulnar border of hand.
Burn, Nov. 18.. ..	Healed in eight weeks	Protopathic loss over little finger, but recovered on palm.
Rubbing the affected parts	Healed Dec. 31 ..	Protopathic clearing rapidly. Loss over little finger. Cleared Jan. 14, 1903.
No definite cause. Sore irritated with oxalic acid	Healed with return of sensation Dec 14	Protopathic loss had begun to clear and soon corresponded almost exactly with the large blister. Protopathic cleared Dec. 14.
Driving..	Healed by Feb. 11, 1903	Oct. 22.—Both forms of sensation began to clear together. Protopathic loss over last two phalanges middle and ring fingers on Nov. 26.
Burn with cigarette ..	Healed by March 1 ..	Protopathic loss index and middle fingers. Had begun to clear rapidly.
None	Healed by March 8 ..	Protopathic loss middle and index fingers.
Pinched finger ..	Healed by July 13 ..	Protopathic loss two terminal phalanges index and middle fingers. Cleared Aug. 28.
None	Healed by March 30 ..	Protopathic loss on index and middle fingers. Not clearing. Cleared by April 27.
None	Healed by Nov. 16.	
?	Healed by Jan. 7, 1903	Protopathic loss over two terminal phalanges of middle finger. Clearing rapidly. Then remained stationary throughout winter. Cleared June, 1903.
.. ..	Nails began to reform Jan., 1902	Protopathic loss over two terminal phalanges index and middle fingers. Cleared May, 1902.
Work as a butcher. No cause known	Healed Dec. 30. No trophic changes after May, 1903	Protopathic loss index and middle fingers. Began to clear March, 1903. Cleared May 24.
All said to be due to burns. These healed, but the finger broke out again when he began to clean pewter with sand and soda water	.. ..	Protopathic loss had begun to clear from palm on March 4, but index and middle fingers were insensitive. May 13, protopathic sensibility lost over one and a half terminal phalanges of middle finger.
Burns during work as a plumber	All healed soundly by Dec. 20, 1903	Protopathic lost completely over thumb, index and middle fingers. Protopathic sensibility returned completely Dec. 20, 1903.

No	Nature of Injury	Nerve United	Nature of Trophic Disturbance
Case 11	Median. Glass cut, May, 1901	May 16, 1902	On July 15, 1901, ulcers were present on thumb, index and middle fingers. Began as blisters; showed no signs of healing. Fresh sores appeared and by April, 1902, two terminal phalanges index and middle fingers, were enlarged, and tip of index was destroyed. No ulcers during two months out of work. Oct.—Middle finger amputation for necrosis of bone. Dec. 21, 1902. Fresh ulcer
Case 10	Median. Glass cut. Primary suture	Jan. 21, 1905	March 15.—Blister on index. Cut on tip of index has formed a small sore. April 19.—Whole tip of finger ulcerated. Terminal two phalanges involved in a large blister
Case 28	Median and ulnar. Glass cut, Sept. 24, 1902	April 17, 1903	March, 1903.—Tips of fingers grew hard and discharged. Placed in hot water they became blistered. April 16.—Nail destroyed; granulating sore. Whole terminal phalanx of index enlarged
Case 60	Complete ulnar, partial median. Glass cut. Primary suture	Nov. 30, 1904	Jan. 14, 1905.—Two blisters on dorsum of little and ring fingers. Jan. 26.—Further blisters appeared
Case 25	Median and ulnar. Glass cut. Primary suture	Dec. 24, 1902	March 8, 1903.—Dorsal surface second phalanx middle and ring fingers scabbed ulcer
Case 67	Partial median and ulnar. Cut wrist with penknife, Oct. 21, 1903. Secondary suture of ulnar	Jan. 11, 1904	Dec. 21, 1903.—Blisters on middle and ring fingers. None elsewhere. These formed ulcers
Case 26	Median and ulnar. Cut with jug. Primary suture	Oct. 26, 1902	March 4.—On tip of index a brown callosity, and on middle finger a blister

injury and infection, these sores heal completely; but comparatively trivial injury will cause them to break out again. The healing differs from that of an ulcer on normal parts only in the slowness of the process. Blisters are liable to form a callosity, which if removed leaves a raw surface. From such a sore, especially when situated in the loose skin on the back of the hand, blood and serum can be expressed by manipulations, insufficient to cause such exudate from a sore healing under normal conditions. The defective elasticity of the skin will cause these sores

Cause Assigned	Result	Condition of Sensation at Time of Appearance of Trophic Change
Worked as a stone sawyer	Jan. 25, 1903, all sores healed, and in spite of work none have appeared since	Protopathic sensibility returned Jan. 25, 1903.
Due to using a knife. April 19. Attributed to hot water	.. ..	Protopathic loss clearing rapidly April 19, 1905.
Work as a carpenter ..	All sores healed after operation, April 17, 1903. Then broke out again and lasted until Dec. 20, 1903	Protopathic sensation began to return by April, 1903. Finally returned Dec. 20, 1903.
?	All healed March 8, 1905	Protopathic sensation began to return to the palm on Feb. 1, 1905.
Burn	Healed by July, 1903	Protopathic sensation returned completely July 12, 1903.
Attributed to hot water into which whole hand was dipped	.. ..	Middle and ring fingers only were analgesic. Protopathic sensibility returned rapidly after secondary suture, but had begun to clear before the operation.
?	Healed by June, 1903	March 4.—Protopathic sensibility showed first sign of returning. Completely returned August, 1903.

to reopen, and a sore on the back of the hand broke open when apparently healed, in consequence of the stretching caused by gripping firmly the handle of a bicycle.

If the patient is engaged on any work that injures his hand, even slightly, these injuries will lead to the formation of ulcers that may necessitate the removal of the finger. A potman who had divided his median nerve cleaned the pewters with silver sand and soda water; the terminal phalanx of the middle finger became an open sore, the matrix of the nail necrosed, and the nail was lost. Another

patient, a plumber by trade, repeatedly burnt the affected fingers in the act of soldering.

But ulcers may make their appearance, when the hand is insensitive to prick, apart from any recognisable injury. Such ulcers always start as blisters which break. Sometimes the contents are serous, but they may be blood-stained and form the so-called "blood blister." Such blisters usually arise at a time when sensibility to prick is beginning to return, but the analgesia has not disappeared from the parts over which the blister is situated.

Whatever their cause, whether they arise from external injury or not, all these defects of nutrition disappear with the return of sensibility to pain, and to the more extreme forms of heat and cold. In the case of a plumber (Case 85)[1] a series of ulcers caused by trivial injuries in his trade had led to destruction of the top of his index finger. The whole of the index and middle fingers except the terminal phalanges had become sensitive to prick by October 25, 1903, and all but the ulcer over the terminal phalanx of the middle finger had healed. By December 20, 1903, the whole hand had become sensitive to painful stimulation, and not only had all the sores healed, but no others made their appearance, although the median area of the hand was still insensitive to light touch and to minor degrees of temperature. This immunity from ulceration existed in spite of work continued under unaltered conditions. Similarly a carpenter who had divided both median and ulnar (Case 28, Table III., p. 160)[2] suffered before and after secondary suture of the nerves from ulcers, caused by burns or by blisters arising from the use of his tools. They troubled him up till the complete return of sensibility to prick, eight months after suture, when they healed firmly and never recurred. In April, 1905, the whole palm and fingers were insensitive to light touch and to minor degrees of temperature; but, whenever he burnt his hand the blister healed as quickly and firmly as on the normal side.

[1] *Vide* Appendix, p. 328.
[2] *Ibid.*, p. 321.

In this connection Case 6 (Table I., p. 152)[1] is of interest. On October 3, 1903, he divided the median nerve of his right hand, together with most of the tendons on the front of his wrist. The divided tendons and nerve were united next day and the wound healed. In January, 1904, blisters appeared on the termination of the index and middle fingers, said to be caused by burns; those on the radial side of the index finger formed shallow ulcers, which did not heal until April, 1904. By April 27, sensibility to prick and to the extremes of temperature had returned to all parts of the hand, but the whole median area of the palm remained insensitive to light touch. He steadily improved until the end of August, when a swelling appeared at the site of the original wound. This was opened and pus evacuated, probably due to infection of one of the silk sutures, by which the nerve had been united. This suppuration threw back the recovery of the hand to such an extent that the two terminal phalanges of the middle and ring fingers became again insensitive to all degrees of temperature and totally analgesic. On October 23, on waking in the morning, he noticed a blister on the terminal phalanx of the middle finger. Excepting that it was entirely insensitive, this finger was not affected the night before when he went to bed. On October 31 the site of the wound was explored by one of us and the nerve was found to be embedded in a mass of fibrous tissue; it was freed and in a month sensation had begun to improve. But on December 18, when he woke in the morning a large blister had appeared on the dorsal aspect of the terminal phalanx of the index finger. This formed a sore, which did not heal until July 1905. By this date, all analgesia had disappeared and the affected parts had become sensitive to prick and to the extremes of heat and cold, but remained insensitive to light touch. From this time no further blisters have made their appearance.

The distribution of these ulcers is a further proof of the close association between trophic defects and the absence of sensibility to pain. Under no circumstances, unless

[1] *Vide* Appendix, p. 300.

complicated by acute sepsis, do they extend beyond the analgesic area. A youth, aged 14 (Case 30, Table IV., p. 164), cut his wrist with broken glass, injuring, but not completely dividing, his median nerve (July 31, 1904). Sensation to prick began to return in September, and by October only the terminal phalanges of the middle and index fingers remained insensitive. On October 12, the skin over the tip of the middle finger broke, forming a sore. On October 22, he cleaned the brass of some bedsteads, using oxalic acid for the purpose. When we saw him four days later the skin over the whole terminal phalanx of the middle finger was raised to form a large blister. This occupied the whole analgesic area and was strictly limited to the parts insensitive to pain. At this time sensibility was returning rapidly and the raw surface healed steadily, keeping pace with the return of sensation. By December 14, it had healed completely and the middle finger had become sensitive to the tip.

That the neuralgia consequent on injury to a nerve may be associated with changes in the skin has been known for nearly a century. In 1813, Alexander Denmark (4) reported the case of a man wounded at the storming of Badajos. The bullet entered 1½ ins. above the inner condyle of the humerus and came out on the outer side, in front of the elbow-joint. No date is given for the onset of the pain, which was intense. "I always found him with the forearm bent and in the supine position, supported by the firm grasp of the other hand. . . ." He described the sensation of pain as beginning at the extremities of the thumb and all the fingers except the little one, and extending up the arm to the part wounded. "It was of a burning nature and so violent as to cause a continual perspiration from his face. He had an excoriation on the palm from which exuded an ichorous discharge."

Although this is an excellent description of the condition so fully described by Weir-Mitchell, Morehouse and Keen (14), under the name of causalgia, Denmark makes no mention of the glossy skin that so commonly accompanies this form of hyperalgesia. The first description of this condition was

given by Hamilton (5) in 1838. He described the pain and tenderness which may follow nerve injuries, and states that they may be accompanied by redness and swelling resembling the appearance of the skin in inflammation of the fascia or a deep collection of matter.

The first complete account of this state occurs in a clinical lecture by Paget (10) delivered in 1864. As some want of apprehension of his teaching has led to subsequent misunderstanding we give his summary in full.

"Glossy fingers appear to be a sign of peculiarly impaired nutrition and circulation due to the injury of nerves. They are not observed in all cases of injured nerves and I cannot tell what are the peculiar conditions of the cases in which they are found; but they are a very notable sign and are always associated, I think, with distressing and hardly manageable pain and disability. In well-marked cases the fingers which are affected are usually tapering, smooth, hairless, almost devoid of wrinkles, glossy pink or ruddy, or blotched, as if with permanent chilblains. They are commonly also very painful, especially on motion, and pain often extends from them up the arm. In most of the cases this condition of the fingers is attended with very distinct neuralgia both in them and in the whole arm, and its relation to disturbance of the nervous condition of the part is, moreover, indicated by its occasional occurrence in cases where neuralgia continues after an attack of shingles affecting the arm."

To Weir-Mitchell, Morehouse and Keen is due the credit of a complete description of a series of cases illustrating this condition. This they published in 1864, in a volume long out of print, but the original description is quoted and amplified by Weir-Mitchell (14) in his book on the "Injuries of Nerves." He says: "The skin affected in these cases was deep red or mottled, or red and pale in patches. The epithelium appeared to have been partially lost, so that the cutis was exposed in places. The subcuticular tissues were nearly all shrunken, and where the palm alone was attacked the part so diseased seemed to be a little depressed and firmer and less elastic than common. In

the fingers there were often cracks in the altered skin and the integuments presented the appearance of being tightly drawn over the subjacent tissues. The surface of all the affected parts was glossy and shining, as though it had been skilfully varnished. Nothing more curious than these red and shining tissues can be conceived of. In most of them the part was devoid of wrinkles and perfectly free from hair. Mr. Paget's comparison of chilblains is one we often used to describe these appearances; but in some instances we have been more strikingly reminded of the characters of certain large thin and polished scars."

In recent years this condition so accurately described by Paget and Weir-Mitchell, and by them associated correctly with pain and tenderness, has been confused with the atrophic conditions that accompany loss of sensibility. Some writers, by the statement that glossy skin is not associated with pain and tenderness, show that they have failed to recognise the essential difference between the condition described by Paget and Weir-Mitchell and the atrophic skin which not infrequently results from division of a peripheral nerve. This confusion is fatal to a comprehension of that condition to which the name "glossy skin" can alone be applied with propriety.

When considering in a previous chapter (p. 245) the hyperalgesia which may follow a nerve injury, we quoted the case of a gunshot wound of the ulnar nerve (Case 63).[1] The whole palm of the affected hand was of a pinkish colour and smooth. The markings were not absent, but the injured hand appeared as if seen through a layer of collodion. Over the dorsal surface of the fingers, particularly over the last two phalanges, the skin was thin and shiny, and the hairs had disappeared. This glossy appearance occupied the thumb, index, middle, ring and little fingers on their palmar aspect and the dorsal surface of the two terminal phalanges of all four fingers.

The palm was intensely tender and hyperalgesia was found over the palmar aspect of the little, ring and middle fingers. On the dorsal surface, the ulnar half of the back

[1] Reported in full in the Appendix, p. 316.

of the hand, together with the whole of the little and ring and the greater part of the middle finger, was intensely tender to pressure or to the point of a pin.

The skin was glossy over an extent somewhat wider than that of the hyperalgesia, but both greatly exceeded the area which subsequently became insensitive after the nerve had been divided (fig. 28, A and C, p. 245).

The characteristic condition of the nails will be dealt with in the next chapter; they were curved and exquisitely tender. On January 30, 1902, the ulnar nerve was dissected at the site of the injury, the two ends freshened and united by a graft. On February 4, the glossy appearance of the skin and all hyperalgesia had disappeared, the sensory state of the hand being that which follows complete division of the ulnar nerve.

True hyperalgesia may exist without the skin becoming glossy, and of the remaining instances cited in Chapter 12, to illustrate this form of tenderness, none were accompanied by this characteristic change. Its full significance can only be determined by an examination of a series of cases, an opportunity that is not likely to occur in civil practice.

We have already dealt with the blisters which are liable to appear over parts totally insensitive to cutaneous stimuli; Weir-Mitchell describes the various forms of eruption that can accompany hyperalgesia. He says: "It was somewhat rare to see any case of glossy skin, especially with causalgia, unattended with vesicles." But in the only complete instance of this condition which has come under our notice, no rash had been present at any time. In one patient who suffered with true hyperalgesia (Case 64)[1] a herpetiform rash was said to have appeared over the little and ring fingers, and ulnar half of the palm, four months before we first saw him.

Chapter 14.—Changes in the Nails Associated with Nerve Injuries.

Since Weir-Mitchell first described systematically the changes in the nails which follow nerve injuries, most

[1] Reported in full in the Appendix, p. 332.

observers have contented themselves with supporting or qualifying his statements.

No one can doubt that the growth and texture of the nails is profoundly affected when a nerve to the hand is injured, but no systematic observations have been instituted to discover the cause of these changes. The general acceptance, overtly or by implication, of some trophic influence exercised by nerves on epithelial structures has led to an absence of that rigid series of control experiments which are necessary, before any such theory can be upheld.

A nerve injury affecting the hand produces a combination of extremely complex conditions. To ensure union of the divided nerve, the arm is placed upon a splint. The muscles of the hand may be paralysed and useless for many months, so that all those movements necessitated by daily life are materially restricted. Division of one or more arteries at the time of the accident may diminish the supply of blood to the hand, and vasomotor changes may result from the nerve injury. Moreover, the fact that nerve influence has been removed from the hand renders that part increasingly sensitive to the vascular influence of cold; it will become blue at temperatures that produce no such effect upon the normal skin. To correct these bad effects the hand is not uncommonly massaged, and we shall show that this also has a material influence on the growth of the nails.

We tried many methods for registering the growth of the nails, but returned to that originally recommended by Weir-Mitchell. A mark is made with nitric acid on that part of the base of the nail which has just emerged from the cover of the skin; week by week we register the passage of this orange streak until it reaches the free edge and is removed by the scissors. Care must be taken that the acid does not excoriate the nails but acts only as an indelible stain. This is not always easy to carry out in practice, in consequence of the different texture of the nails of the sound and affected hands. If the nails are rough, an application which scarcely stains the normal nail will burn those that are abnormal; or the density and firmness, noticeable in nails in which growth has been long delayed, may render

staining difficult without repeated application. After the acid has been placed upon the nails, it is well to wait until the stain begins to appear; then the hand should be well washed and dried before the patient is dismissed, to make certain that the acid does not continue to act harmfully.

Immobilisation of the hand upon a splint retards profoundly the growth of the nails. After a fortnight, the nails on the free hand may have grown to three times the extent of those on the hand that was restrained. These changes are so startling, and have so completely failed to attract attention, that we give shortly the details of some of our most satisfactory observations. It will be seen that the

TABLE VIII.

No.	Age	Sex	Fracture	Days in Splints	Growth of Nails	
					Affected Side	Normal Side
Case 68	57	M.	Right Colles'	14	1 mm.	3 mm.
Case 69	52	M.	Right Colles'	14	0	1·5, 1·0, 0·5, 0·5, 0·5 mm.
Case 70	33	M.	Right radius	14	1 mm.	2 mm.
Case 71	16	M.	Left radius	21	2·5 mm.	3·5 mm.
Case 72	12	M.	Left radius	14	0·5 mm.	2 mm.
Case 73	9	F.	Right ulnar	21	2 mm.	3·5 mm.
Case 74	48	M.	Left radius	28	0	2·5 mm.
Case 75	9	F.	Right radius and ulnar	14	0·5 mm.	1·5 mm.
Case 76	9	M.	Left radius and ulnar	14	0	1·5 mm.
Case 77	10	M.	Separated lower epiphysis of left humerus	14	1·5 mm.	2·5 mm.
Case 78	7	M.	Separated lower epiphysis of left humerus	21	2 mm.	3 mm.
Case 79	13	M.	Shaft of left humerus	28	3 mm.	4 mm.
Case 80	54	M.	Shaft of left humerus	28	0	3 mm.

On this table one number only is given, whenever the nails on all the fingers grew to the same amount. But if they grew differently on any of the fingers, the measure of their growth is given in a series beginning with that of the thumb.

patients were of diverse ages, and the injuries for which the arm was placed in the splint ranged from fracture of the humerus to fracture of the lower end of the radius. In no case was the growth on the two sides even approximately equal, and the uniformity of growth in all the nails of the quiescent hand was remarkable. This diminution of growth is not due to any change in the blood supply of the arm, produced by either bandages or splints, for if the arm is bandaged to a splint, but the hand left free, growth is not materially retarded.

In No. 75, in consequence of fracture of the right radius and ulnar, the arm was placed on a splint with the hand immobilised for fourteen days; in this time the nails had grown three times as much on the left as on the right hand. For the next twelve days the right arm remained on the splint but the hand was freed, and the patient was encouraged to move the fingers. Growth was now equal in the nails of both hands (1·5 mm.). For this reason a sling makes no material difference to the growth of the nails, provided that it is not used in consequence of some affection tending to cause restriction in the movements of the hand. A boy, aged 9 (Case 76), fractured his left radius and ulnar; he was put into splints for fourteen days, during which time the nails of the left hand did not grow to any measurable amount. During the next eight days the arm was kept in a sling, but the nails grew equally on both hands.

Massage causes little definite increase in the growth of the nails of a hand in ordinary daily use. A healthy young woman who had no daily occupation attended the massage department regularly from August 10 to September 21. Her left hand was rubbed for twenty minutes, three times a week, but it is impossible to say that this treatment made any perceptible difference to the growth of her nails.

Forty-six Days without Massage.

	Left.	*Right.*
Thumb	5 mm.	5 mm.
Index	5 mm.	5 mm.
Middle	5 mm.	6 mm.
Ring	5·5 mm.	6 mm.
Little	5 mm.	5 mm.

Forty-two Days, Left Hand Massaged Three Times a Week.

	Left.	*Right.*
Thumb	6 mm.	7 mm.
Index	6 mm.	6 mm.
Middle	6 mm.	6 mm.
Ring	6 mm.	6 mm.
Little	5 mm.	6 mm.

But if the hand is protected from the cold and rubbed repeatedly, the nails may grow excessively, even though the arm remain in a sling. Of this, Case 80 is an excellent instance. This man fractured his left humerus, and during the twenty-eight days his arm remained in splints the nails of his left hand did not grow appreciably. During the following fortnight, the left arm was kept in a sling, but the hand and arm were massaged every second day. At the end of fourteen days the growth was as follows:—

	Left (*affected*).	*Right* (*sound*).
Thumb	2 mm.	1 mm.
Index	4 mm.	0·5 mm.
Middle	4 mm.	0·5 mm.
Ring	4 mm.	1 mm.
Little	3 mm.	0·5 mm.

Throughout the next two weeks he wore no sling, and the hand was rubbed five times only.

	Left (*affected*).	*Right* (*sound*).
Thumb	2 mm.	1·5 mm.
Index	1 mm.	2 mm.
Middle	1 mm.	2 mm.
Ring	1 mm.	1·5 mm.
Little	1·5 mm.	2 mm.

In this instance, the return of the hand to its ordinary uses threw back the growth of the nails to a figure on the whole slightly below that of the normal hand. This is an unusual experience; more commonly, the nails of the two hands grow equally if the hand is kept in a sling and massaged every second day.

Thus, whilst immobilisation of the hand on a splint measurably retards the growth of the nails, massage does

not universally produce a corresponding increase, provided the hand be normal.

But, when the hand is paralysed or incapacitated from sharing to the usual extent in the necessary movements of daily life, regular massage tends to prevent the extreme retardation of growth that would otherwise occur, and the nails may grow only slightly less rapidly than those of the normal hand.

Muscular paralysis alone will greatly retard the growth of the nails, and probably for this reason irregularity of growth is so manifest a consequence of division of the ulnar nerve. This we had hoped to show from cases of motor paralysis affecting the hand due to destruction of the anterior horns of the spinal cord. But instances where anterior poliomyelitis has affected one hand only so gravely that all movement has been destroyed, are uncommon; the following case shows how considerable may be the retardation of growth from this cause. A child of four years old became suddenly ill in July, 1902, and four days later the right arm and hand were found to be useless.

In February, 1903, she showed all the signs of the paralysis due to anterior poliomyelitis. The right arm was flaccid; the muscles of the shoulder were not acting, with the exception of the upper part of the trapezius. She could slightly extend the middle and ring fingers, but could make no other movement of the hand, forearm or arm. During the summer the hand was neither blue nor cold, but throughout the winter months it was constantly somewhat colder to touch than the normal hand. All forms of sensation were perfect, including the sense of passive position. From February 11 to May 13, a period of ninety-one days, the growth of the nails was almost twice as great on the sound as on the paralysed hand.

	Right (affected).	*Left (sound).*
Thumb... ...	... 5 mm. ...	... 8 mm.
Index	... 5 mm. ...	... 8 mm
Middle... ...	... 5 mm. ...	... 9 mm.
Ring	... 5 mm. ...	... 9 mm.
Little	... 4 mm. ...	... 7 mm.

During seventy-seven days (from November 4 to January 20) the growth maintained almost exactly the same proportion, showing that the defect was not due to coldness of the hand.

	Right (affected).	*Left (sound).*
Thumb	5 mm.	7 mm.
Index	4 mm.	7 mm.
Middle	4·5 mm.	7 mm.
Ring	4·5 mm.	7 mm.
Little	4 mm.	5·5 mm.

Whenever we marked the nails of the affected hand we also marked those on the sound side. By this means we gradually accumulated a large number of observations on the growth of normal nails extending, in seventeen cases, over a period of more than a year. Several of these patients remained under observation consecutively for three years. We noticed that the rate of growth differed considerably from time to time, and expected to find that this variation was coincident with the seasons of the year. In a few instances it certainly seemed that the nails grew more rapidly between May and July, and more slowly between November and March. But of the whole seventeen cases only six came within this category, and since normally the growth of the nails is liable to inexplicable variations, we do not consider that our observations are sufficient to establish any such general rule.

So far we have examined only the result of immobilisation and of other conditions acting on a hand whose nerves were uninjured and have shown that limitation of movement is a potent influence in retarding the growth of normal nails.

Turning to cases of complete division of one or more nerves of the hand, we find that want of movement is also the prime factor in the profoundly altered growth of the nails which follows any lesion causing paralysis.

Division of a sensory nerve alone produces no change in the growth of the nails that spring from the fingers which have become completely insensitive.

Case 81.—*Division of the digital branches of the median and ulnar nerves supplying the ring finger. Total loss of cutaneous sensibility over the two terminal phalanges. Absence of any alteration in the growth of the nail of the affected finger.*

On October 12, 1903, whilst working as a cabinet maker, G. W. cut the palm of his hand with a chisel. He came the same night to the London Hospital and two tendons were sutured; the wound is said to have healed well.

When he first came under our notice on December 16, 1903, a longitudinal scar ran from the head of the fourth metacarpal bone to $\frac{1}{2}$ in. (about 1·2 cm.) below the fold of the wrist. This scar, about $2\frac{1}{2}$ ins. (6·5 cm.) in length, was crossed somewhat obliquely at about its centre by a second smaller scar.

None of the intrinsic muscles of the hand were paralysed or wasted and the tendon of the flexor sublimis that went to the ring finger had united perfectly.

From the moment of the accident, he recognised that the ring finger was numb. The whole of the skin over the two terminal phalanges we found to be insensitive to prick and to all forms of heat and cold; the area of insensibility to light touch corresponded on the dorsal surface of the finger to this analgesia but extended on the palmar aspect as far as its base.

A rounded ulcer with thickened edges and a smooth granulating floor was situated over the palmar aspect of the terminal phalanx of the ring finger, evidently healing slowly.

For forty-two days the condition of sensation did not change materially. In this time the nails grew but slightly less on the affected finger than on that of the sound hand. Moreover, this small difference was found in all the four fingers and can be accounted for most probably by some want of use.

	Left (*affected*).	*Right* (*sound*).
Thumb	4·5 mm.	4·5 mm.
Index	4·5 mm.	5 mm.
Middle	4 mm.	4·5 mm.
Ring	4 mm.	4·5 mm.
Little	3 mm.	3·5 mm.

In the case of one of us, where the radial and external cutaneous nerves were divided at the elbow, the nail of the thumb grew to exactly the same extent on the two sides, although the nail-bed and dorsal surface of the thumb were insensitive to all cutaneous stimulation.

Division of the median nerve at the wrist without injury to the tendons is an occasional accident. In such a case it will be found that the nails grow equally on the two sides. Thus after suture of the divided median nerve, A. C. (Case 4, Table I., p. 152) was kept for thirty-five days on splints. During this time the nails grew to the following amount :—

	(Left affected).	*Right (sound).*
Thumb	1 mm.	5·5 mm.
Index	1·5 mm.	5·5 mm.
Middle	1 mm.	5 mm.
Ring	2·5 mm.	5 mm.
Little	3 mm.	5·5 mm.

But in the thirty-nine days which followed they grew equally, in spite of the absolute loss of cutaneous sensibility in the index and middle fingers produced by the nerve injury (*vide* fig. 3, H, p. 136).

In Case 13 (Table I., p. 152) we had the opportunity of measuring the growth of the nails after the median nerve had been divided without injury to the tendons, and found that they grew equally on the two sides. Then the wound was explored and the two completely separated ends were freshened and reunited.

For sixteen days the hand remained in splints and the nails grew to the following amount :—

	Right (affected).	*Left (sound).*
Thumb	1 mm.	3 mm.
Index	2·5 mm.	3 mm.
Middle	1·5 mm.	3·5 mm.
Ring	2·5 mm.	3 mm.
Little	2 mm.	3·5 mm.

But as soon as the hand was freed, the nails again grew equally, in spite of the total cutaneous insensibility of the index and middle fingers.

Complete loss of sensibility to light touch and to the minor degrees of heat and cold makes no difference to the growth of the nails. In Case 12 (Table I., p. 152, and fig. 3, F, p. 136) all sensation to light touch was lost over the full median area and yet for sixty-three days the nails grew

equally on both hands. During this period all movements of the hand were perfect except those of the abductor and opponens pollicis.

Sometimes an incomplete division of the median produces the full loss of sensation that usually follows complete division of the nerve, without muscular paralysis. An instance of this condition is to be found in Case 29.[1] This youth showed to a profound degree the influence of immobilisation. During the thirty-two days after the operation when the hand remained on a splint the nails grew very little on the affected side.

	Left (affected).	*Right (sound).*
Thumb	1·5 mm.	4 mm.
Index	0 mm.	2 mm.
Middle	0 mm.	2·5 mm.
Ring	1·5 mm.	3·5 mm.
Little	2 mm.	3 mm.

But during the following thirty-five days the nails on the two hands grew equally in spite of the loss of sensation.

Loss of sensation alone, whether complete or partial, makes no material difference to the growth of the nails. How, then, are we to explain the profound alteration produced by division of the ulnar nerve?

A characteristic instance of this defective growth was seen in Case 63, where sensation was lost over the full ulnar area (fig. 1, H, p. 127). No tendons were divided and the following differences must have been due solely to the consequences of division of the ulnar nerve. In one hundred and thirty days, during which sensation showed no sign of return, the growth was as follows :—

	Right (affected).	*Left (sound).*
Index	16 mm.	16 mm.
Middle	15 mm.	17 mm.
Ring	11·5 mm.	14·5 mm.
Little	10 mm.	14 mm.

But this result, so characteristic of lesions of the ulnar nerve, cannot be due to any direct effect of the nerves upon

[1] Reported in full in the Appendix, p. 302, *vide* also Table IV., p. 164.

the growth of the nails; for in a woman, aged 36 (Case 23, Table II., p. 158), in whom the ulnar nerve had been reunited, the change was equally definite, although all sensation had returned. But at this time none of the muscles of the hand supplied by that nerve were acting voluntarily.

	Right (affected).	*Left (sound).*
Index	7 mm. ...	... 8 mm.
Middle	6 mm. ...	... 8 mm.
Ring	5 mm. ...	... 9 mm.
Little	4 mm. ...	... 7 mm.

Here the paralysis alone must have been the cause of this difference in growth, a difference which can be partly prevented by the use of regular massage. Case 19,[1] shows how closely the deficient growth after division of the ulnar nerve depends upon want of movement. At first, during the thirty-four days the hand was on splints, the nails grew to the following extent:—

	Left (affected).	*Right.*
Thumb	1·5 mm. ...	... 4 mm.
Index	1 mm. ...	... —
Middle	2·5 mm. ...	... 4 mm.
Ring	2·5 mm. ...	... 4 mm.
Little	2 mm. ...	... 4 mm.

During a period of forty-nine days, when all sensation was lost over the ulnar area, their growth was as follows:—

	Left (affected).	*Right.*
Thumb	6 mm. ...	... 7 mm.
Index	6·5 mm. ...	... 7 mm.
Middle	6·5 mm. ...	... 6·5 mm.
Ring	6·5 mm. ...	... 6 mm.
Little	5 mm. ...	... 6 mm.

But during this time the hand was massaged regularly three times a week. Later this treatment was discontinued, and for forty-nine days he relapsed into the deficient growth so characteristic after division of the ulnar nerve.

[1] Reported in full in the Appendix, p. 309.

	Left (affected).	*Right.*
Thumb	6 mm.	5 mm.
Index	4 mm.	5 mm.
Middle	4 mm.	6 mm.
Ring	3 mm.	6 mm.
Little	1·5 mm.	4·5 mm.

The fact that the nails of the middle, ring and little fingers, and not infrequently that of the index, are affected after injury to the ulnar nerve is sufficient alone to show that its sensory branches can have little to do with this characteristic change.

In conclusion, we believe that the most potent cause of diminished growth in the nails after division of a peripheral nerve is want of movement. Whenever the skin becomes insensitive and the injury has not divided tendons or paralysed muscles, the nails do not show any deficiency in growth. The profound alteration that follows division of the ulnar nerve is produced by paralysis of the intrinsic muscles of the hand, and stands in no relation to the loss of sensibility.

When the skin of the hand becomes glossy and when hyperalgesia is well developed, the nails undergo a change radically different from that seen after division of a nerve. Weir-Mitchell says: "When the depraved nutritive state (glossy skin) has lasted for some months, the hair commonly disappears from the fingers affected, and the nails undergo remarkable alterations. . . . The alteration in the nail consists of a curve in its long axis, an extreme lateral arching, and sometimes a thickening of the cutis beneath its extremity. In other cases a change takes place which is quite peculiar, or which to us at least was new. The skin at that end of the nail next to the third finger joint becomes retracted, leaving the sensitive matrix partly exposed. At the same time the upper line of union of skin and nail retreats into or under the latter part, and in place of a smooth edge is seen through the nail as a ragged and notched border."

In the only instance of true glossy skin that has come under our notice (Case 63) the nails of the little and ring and middle fingers curved longitudinally and horizontally.

They were not ribbed but were thin and exquisitely tender. The patient was certain that these nails grew faster than those on the sound hand; but owing to the shortness of the period during which he was under our observation before the nerve was divided and sutured, we were unable to verify his statement by measurement. The remaining instance of hyperalgesia did not affect the tips of the fingers, and threw no light on this increased growth of the nails. But whenever a curved nail is growing slowly it is thick and hard. In the case of L. G. H. (No. 63) the nails were, on the contrary, smooth and thin, collateral evidence that they were growing faster than normal.

Chapter 15.—Paralysis and other Muscular Changes.

The motor supply of one nerve rarely overlaps that of another, and can be readily determined by dissection. The examination of cases where a peripheral nerve has been divided has not led us to doubt the usual teaching concerning the supply of any of those muscles of the limbs that have come under our observation. This chapter will therefore be devoted mainly to a consideration of the time required for the recovery of muscular power, the disappearance of the wasting and the restoration of irritability to the interrupted current.

Before passing to the results of our observations, we wish to call attention to some possible sources of error in the methods usually employed to determine whether a muscle is acting voluntarily.

The little finger is abducted by the combined action of two muscles, the abductor and the extensor minimi digiti. If the former is paralysed, as is the case after division of the ulnar nerve, false abduction can be produced by means of the extensor. The nature of this movement can be at once recognised by the extension which accompanies it. When the hand is placed flat on the table the little finger is seen to be raised if the abduction is caused by the extensor only.

Another fruitful source of error, as pointed out by Beevor (1), is false abduction of the thumb by means of its extensor muscles. True abduction of the thumb takes place in a plane at right angles to that of the palm, and this is the action of the abductor pollicis. But under ordinary circumstances this muscle acts in combination with the extensors, and when the abductor and opponens pollicis are paralysed from division of the median nerve, the extensor muscles alone can produce some abduction. The true nature of this movement is betrayed by the impossibility of performing it without extending the thumb.

In like manner, the movement produced by the opponens can be simulated by contraction of the flexor longus pollicis and of the adductors of the thumb. The true mechanism of this movement can be recognised by the flexion of the terminal phalanx with which it is associated.

The index finger can be abducted slightly by means of its extensor, and this may cause some difficulty, after division of the ulnar nerve, in determining whether the first dorsal interosseous is acting.

Another difficulty in connection with this muscle arises when it is tested electrically. After the ulnar nerve has been divided the first dorsal interosseous muscle wastes. But in the position of the wasted muscle, contraction can be frequently obtained by means of the interrupted current. This is due to stimulation of the first lumbricalis inserted into the dorsal expansion of the extensor tendon and supplied by the median nerve.

Division of a motor nerve causes immediate paralysis in the muscles it supplies. But they continue to react to the interrupted current for from three to five days. After the fourth to the seventh day we obtained no response to the interrupted current in the muscles of the hand supplied by the median or by the ulnar nerve. Here our experience coincides with that of Bowlby (2), who states that he has been unable to obtain any reaction to the strongest current as early as the third or fourth day after division of the nerve. Statements assigning a considerably later date are probably vitiated by the inclusion of cases of injury or incomplete

division of a nerve. In about ten days it may be extremely difficult to obtain any response from the paralysed muscles by means of the constant current; or the characteristic sluggish contraction may begin to make its appearance shortly after all reaction to the interrupted current has been abolished.

After complete division of the ulnar nerve all the muscles of the hand become paralysed except the two radial lumbricales and the abductor and opponens pollicis. The muscles affected waste, and the hand assumes the appearance so characteristic of this injury. The little finger is abducted and somewhat over-extended at the metacarpo-phalangeal joint; the remaining fingers are slightly extended at the same joint, and are out of alignment with one another. A striking feature is the profound wasting in the first interosseous space.

In five cases of primary suture of the ulnar where we were able to prove that the nerve had been completely divided, the period at which motion first returned to the paralysed muscles was, on an average, 346 days.

It so happened that in each of these cases contractility to the interrupted current was rediscovered for the first time on the same date as the return of voluntary power.

Of these five patients, two disappeared before the hand had again become completely normal in appearance. But in the remainder the wasted muscles had been restored, and the hand had regained its usual appearance in twelve months (Case 22, Table II.), twenty months (Case 14, Table II.), and two years (Case 15, Table II.).

Of all the patients we have examined, in whom the median nerve was completely divided, we have been able to follow three only to the end. Voluntary power returned to the outer thenar group of muscles on an average in 272 days (237, 282, 299). In two instances the first reaction to the interrupted current was noted on the same date as the return of voluntary power; in one, it was rediscovered five weeks before any voluntary contraction could be observed. One patient recovered so completely, that fifteen months after primary suture no difference could be noticed in the

divided, the muscles first responded to the interrupted current shortly before any voluntary contraction could be obtained. One case only showed any return of voluntary power before a reaction was obtained to the interrupted current.

Voluntary power ultimately returned to all the paralysed muscles in every patient whom we have observed from the time when the nerves were sutured.

In order to discover if, in some instances, the paralysed muscles did not recover, we examined a number of patients in whom primary suture of one or more of the nerves to the hand had been performed at the London Hospital before the beginning of our research. Of four cases where the ulnar had been divided, one showed complete paralysis of all the muscles supplied by that nerve five and a half years after its suture. All the others had recovered when first seen by us from two to four years after the injury.

Five of the six patients in whom the median nerve had been divided had completely recovered when we first saw them two to four and a half years after suture; one still showed no return of motor power eighteen months after the nerve had been reunited.

Thus, we may say that most patients regain voluntary power in the affected muscles after primary suture of one or more of the nerves of the hand; but the strength of the contraction and the ability of the hand not infrequently remain permanently less than normal.

Primary suture implies the reunion of the ends of a nerve within a few hours of its division; the only variable in the case is therefore the period necessary for the return of function. But secondary suture may be carried out at the most diverse periods from the date of injury. This involves a second variable factor; for it is desirable to determine, if possible, not only the date of return of function, but also the effect produced upon this return by the length of time during which the nerve has remained completely divided.

A general statement of the results of secondary suture necessitates an investigation of numerous instances, but in the majority of patients the nerves are sutured before the

appearance of the two hands. But, in another instance, some wasting was still visible two and a half years after suture.[1]

In every patient watched by us to complete recovery, after coincident division of the median and ulnar nerves, the wound suppurated to a greater or less extent. This probably accounts for the considerable diversity in the time required among the three instances for the return of voluntary power to the paralysed muscles. But, however these cases differ from one another, they have one feature in common; both voluntary power and reaction to the interrupted current returned earlier in the opponens and abductor pollicis than in any of the muscles supplied by the ulnar nerve. The period necessary for the return of voluntary power in these three complete cases was 273, 356, and 605 days, whilst a response was obtained to the interrupted current in 273, 308, and 728 days respectively.

Among these cases of coincident division of the median and ulnar nerves, one patient only recovered so completely that no difference could be noticed between the two hands; this condition was reached two and a half years after suture of the nerve. Another patient, in whom the wound suppurated badly (Case 27, Table III.), still showed some wasting of the thenar eminence and interosseous spaces four years and five months after the nerves had been united.

Thus, as far as the muscles of the hand are concerned, it would seem that voluntary power returns earlier when the median nerve is divided. After coincident division of both nerves, the opponens and abductor pollicis are restored more quickly than the muscles supplied by the ulnar nerve.

Out of eleven cases of primary suture after division of one or more nerves to the hand, in eight the muscles first reacted again to the interrupted current at the same date on which the first voluntary contraction was observed. In one instance of division of the median (Case 3, Table I.), and in one (Case 26, Table III.) where both nerves had been

[1] We wish to call attention to a possible source of error after division of the median nerve. That branch which supplies the muscles of the hand may leave the main stem of the nerve in the lower part of the forearm, and thus escape injury when the wound is at the wrist. We have seen such a branch uninjured in one instance (Case 5, Table I.) at the operation for primary suture.

complete section. Whenever the nerve is injured severely, recovery takes place extremely slowly ; in the only instance where it was completely divided voluntary power had not returned to the paralysed muscles three and a half years after the ends of the nerve had been reunited.

When a nerve is incompletely divided the injury may produce the most varying results upon muscular power and on the reaction to electrical stimulation. In many cases voluntary power may not be lost in the muscles supplied by the injured nerve, and they may react normally to both forms of electrical stimulation. Voluntary power may remain, but reaction to the interrupted current be lost; the muscles will then respond more readily to the constant current. The contraction still occurs to the negative pole more readily than to the positive, but the strength of current necessary to cause contraction is considerably reduced. This facile reaction to the constant current also occurs after incomplete division of the nerve when voluntary power is lost, and all response to the interrupted current is abolished. It is therefore a valuable indication that the nerve has not been completely severed.

Chapter 16.—Theoretical.

The observations detailed in the previous chapters are so completely out of accord with any view of the mechanism of sensation as yet put forward that it will be well to summarise the facts before attempting to co-ordinate them into a new theory.

It has long been known that, when a nerve to the hand is divided, some sensibility to pressure with the finger still remains, even in parts insensitive to the prick of a pin. This fact led Létiévant (8) to enunciate his theory of "supplementary sensation" (*sensibilité supplée*). In the early 'sixties, "cette époque de foi robuste," surgeons brought forward cases of return of sensation and motion within a few days, or even hours, after reunion of a divided nerve. Létiévant demonstrated by a series of cases that this so-called return was due in reality to the retention of sensation

accidental wound has healed, and cases of secondary suture are rare. We have as yet been able to follow six patients only up to complete recovery of voluntary power and muscular reaction. Among them the time at which the ends of the nerve were reunited varied from 15 to 502 days after division.

The following table shows these cases and the time of their recovery :—

Ulnar Nerve.

	Period after Division at which Secondary Suture was Performed.	Return of Voluntary Power.	Return of Reaction to the Interrupted Current.
No. 18	15 days	702 days	702 days.
,, 23	28 ,,	408 ,,	408 ,,
,, 24*	502 ,,	370 ,,	370 ,,

Median Nerve.

No. 85*	66 days	816 days	635 days.
,, 12	153 ,,	481 ,,	369 ,,
,, 11	375 ,,	373 ,,	373 ,,

It will be noticed that there is no instance among them of that remarkable recovery of muscular power recorded by Kennedy (7) after secondary suture. The earliest return of voluntary power occurred in 370 days after the nerves had been reunited.

We possess among our records one complete case of secondary suture of the musculo-spiral nerve (No. 43, reported in full in the Appendix). Voluntary power reappeared in the paralysed muscles 272 days after the ends of the nerve had been reunited. This boy was intolerant of the interrupted current, and no contraction could be obtained to this stimulus until fifty-eight days later; the muscles then reacted well even to weak currents such as he bore with equanimity.

The external popliteal is not infrequently injured by a crush of the leg, or as a consequence of fractures below the knee. Such injuries do not usually cause complete division of the nerve, and in one instance only were we able to watch the results caused by reunion of the divided ends after

* Reported in full in the Appendix.

over the affected parts. When the median nerve was divided, stimulation with the feathers of a quill or with the head of a pin could be appreciated in some cases over the whole area supplied by that nerve, including even the fingers. But these parts were entirely insensitive to temperature, and the compass points could not be discriminated even when 6 cm. apart.

He showed that, after division of the median nerve, the movement resembling opposition of the thumb was due to contraction of its adductor and flexor muscles. He also recognised false abduction, attributing it to "l'action du long abducteur du pouce" (extensor ossis metacarpi pollicis).

On the sensory side, he believed the absence of complete insensibility was due to anastomosing branches and to the conduction of mechanical vibrations on to neighbouring parts where the nerve end organs were intact.

His observations were correct and his criticisms just. But unfortunately surgeons failed to appreciate the significance of this work, although ready to invoke "supplementary sensation," when the condition of sensibility did not accord with their expectations. Thirty years after the publication of Létiévant's book, neglect of his warning has led to the advent of another generation of robust believers, who report cases where suture of divided nerves has led to immediate or strikingly rapid return of sensation.

Létiévant and his contemporaries knew nothing of afferent fibres running with motor nerves, and to them the conception of deep sensibility put forward by us was therefore impossible. But, after Sherrington's demonstration (13) of the existence of such afferent fibres, we were compelled, early in our research, to examine their function in man; for such fibres may remain uninjured after complete destruction of all the nerves to the skin.

This led to the division in one of us of the radial and external cutaneous nerves and to a series of observations to be reported in full later in conjunction with Dr. Rivers. The knowledge of the properties of deep sensibility, gained from this experiment, enabled us to understand the full significance of the various forms of residual sensation, discovered after division of peripheral nerves.

Complete division of all the sensory nerves to the skin leaves the part sensitive to those stimuli commonly employed by the surgeon as a test for sensibility to touch.

All forms of pressure, such as a touch with a pencil or the feathers of a quill, can be appreciated and localised with considerable accuracy. Two points applied successively can be recognised, but, if applied simultaneously, the patient entirely fails to discriminate them, even when the compasses are widely separated. The denervated part is insensitive to all forms of heat and cold. Pain can only be evoked by pressure, and then has that peculiar aching character associated with a crush or contusion.

We have shown that this deep sensibility is restored rapidly, and seems to reach the hand by way of the tendons and fibrous structures connected with them. Division of the median nerve without injury to these structures leaves the response to all forms of pressure almost unaffected.

Clear recognition of these facts is necessary before we can attempt to explain the condition of cutaneous sensibility after division of a peripheral nerve. Stimulation can rarely be made without some pressure, but every stimulus must be of so specific a nature that the pressure element in the sensation passes into the background. A pin-prick may be appreciated and localised, but, unless it is recognised as causing pain, its appreciation may have been entirely due to deep sensibility. To say that "a prick with a pin was felt and well localised" is no evidence of the presence of cutaneous sensibility to pain.

We have shown that when a nerve, such as the median or ulnar, is divided, the area it supplies does not become uniformly insensitive.

All previous observers have stated that sensation is diminished over the full area usually assigned to the injured nerve, and lost completely over a small portion only. We have shown that this "diminution of sensation" is, in reality, a total loss of sensibility to stimulation with cotton-wool, to the compass test, and to the painless interrupted current. Moreover, this area of "diminished" sensation is insensitive to degrees of temperature between about 22° C.

and 40° C., although within its borders ice and water at 50° C. can be appreciated.

Moreover, if a nerve has been completely severed, recovery of sensation does not take place, as is usually believed, by a gradual increase in sensibility, beginning in parts where sensation has never been lost entirely; but the hand first becomes sensitive to prick and to the more extreme forms of heat and cold. Only after an interval of some months do the higher forms of sensibility begin to return.

The intermediate zone and a hand in the first stage of recovery are alike in their insensibility to cotton-wool and to temperatures between about 25° C. and 40° C.; the compass test fails utterly, even when the points are separated to many times the distance necessary upon the normal hand. All the finer and more delicate sensations involving discrimination and differentiation are wanting. Alike in these defects, the sensibility of the intermediate zone and that of the recovering hand resemble one another in the peculiar character of their response to stimulation. A prick causes immediate withdrawal of the hand with evident signs of discomfort, and the sensation it produces is badly localised, radiating widely over the parts affected. Stimulation with temperatures below 20° C. evokes a sensation of cold which radiates widely and is of a tingling character. If the point of a pin is dragged lightly across the skin from normal to abnormal parts, sensation changes immediately the line is crossed at which light touch is no longer recognised. There is no gradual passage from parts of normal to those of abnormal sensibility; the line of transition is abrupt.

But, although the intermediate zone and the hand at the end of the first stage of recovery resemble one another in their want of response to the more delicate forms of stimulation and in the wide radiation of any sensation evoked from them, they differ in one important particular. An intelligent patient is aware that sensibility is materially diminished, even to the point of a pin, over the intermediate zone. He speaks of the skin of this area as "numb, but not dead." But from parts that have reached the end of the first stage of recovery the response to the point of a pin is

greater than that from the normal skin. A prick causes instant withdrawal of the hand, with evident signs of extreme discomfort. Ice and water at 50° C. seem respectively colder and hotter over the affected area than over normal parts of the hand. Sensation is less acute, but more vivid than that from the normal skin.

Thus the sensibility of the intermediate zone and that of the recovering hand are similar in kind; but, whilst the latter reacts more briskly than normal to its peculiar stimuli, sensation over the intermediate zone is obviously defective. The intermediate zone, apart altogether from its insensitiveness to light touch, may be rightly spoken of as an area of diminished sensibility.

This form of sensibility, so characteristic of parts to which sensation is returning, we call *protopathic*.

It will be well to formulate the essential characteristics of this form of sensibility as manifested in a hand that has reached the end of the first stage of recovery. Every stimulus, to which the part reacts, produces a sensation that radiates widely and is accompanied by a peculiar tingling quality. The point of stimulation is recognised with considerable accuracy in consequence of the sensibility of the subcutaneous structures to the pressure that necessarily accompanies almost every stimulus. But the specific sensation of pain, of cold, or of heat, seems to be situated in some remote part, such as the fingers, or to extend widely over the palm. Sometimes an intelligent patient will say: "You touched me on the palm, but the prick is all over the fingers." As far as we have observed, the radiation never spreads to parts over which light touch is perfect and the compass test gives a normal record; conversely, a prick over normal parts does not produce any sensation within a contiguous area of protopathic sensibility.

Although parts in this condition react more vehemently to painful stimulation than those that are unaffected, the stimulus necessary to evoke sensation appears to be greater. When the normal hand is pricked with a pin, a sensation of sharpness is produced almost as soon as the point touches the skin. Over protopathic parts the point must be applied

more firmly before pain is produced, and this sensation not only arises more slowly, but lasts after the stimulus is removed. The widespread, aching pain produced by a prick of just sufficient force to arouse the sensibility of a protopathic area is more intolerable than the sensation caused by a prick of considerable violence over normal parts. The patient cries out, and withdraws his hand rapidly. Thus, although a stronger stimulus is necessary to evoke a painful response from parts in a condition of protopathic sensibility than from those where sensation is normal, the discomfort manifested by the patient is obviously greater.

Temperatures below 40° C. do not, as a rule, evoke a sensation of heat from parts in this condition, when the patient belongs to the ordinary hospital class. But, in one of us, the back of the hand, endowed only with protopathic sensibility, habitually reacted to 38° C. over one small area of maximal sensibility. Over parts at the end of the first stage of recovery, water at 45° C. will certainly be recognised as warm during the summer months; but over the intermediate zone with its lowered protopathic sensibility, or when the cold of winter has rendered the affected parts less sensitive, a temperature of 50° C. may be required before any sensation of heat is produced. Such a temperature is capable of producing pain, even over the normal hand, and it might be objected, that the sensation it produces over such protopathic parts is in reality one of pain rather than of temperature. But the patient states, that though pain and tingling are evoked by stimuli at this temperature, they are accompanied by a definite sensation of heat.

An area supplied only with protopathic sensibility reacts more vehemently than normal parts to all temperatures capable of evoking a response. If a test tube containing water at 45° C. is moved across the hand from normal to abnormal parts, it appears to become hotter as soon as the protopathic area is reached. And yet this same area is totally insensitive to water at 35° C., which is decidedly warm to the normal hand. Thus, the increased reaction to 45° C. over the protopathic area is in no way due to an increased sensitiveness to heat as a whole.

This over-action to the more extreme degrees of heat can be well shown at a somewhat later stage of recovery. The hand may then have regained some sensibility to warmth, (34° C. to 38° C.), but still shows the characteristic response to prick, and a sharp line of change to the point of a pin dragged across the skin. If, when the hand is in this condition, a test tube containing water at 45° C. is passed across the palm, it appears to grow hotter over the protopathic area. But when the same procedure is carried out with a test tube at 37° C. it appears to grow cooler as soon as the affected parts are reached. The recovering parts in this experiment react less briskly to the one temperature (37° C.) and more briskly to another (45° C.) than parts of normal sensibility.

To cold stimuli, especially when the temperature is below 18° C., the reaction of protopathic parts is equally characteristic; no stimulus produces more striking radiation and diffusion. The sensation of cold appears to extend widely, or to be situated in some distant part of the affected area. Moreover, the reaction produced by temperatures below 18° C. is greater over protopathic than over normal parts; the stimulus seems to the patient to be colder.

If the affected part happens to be endowed with hair, it will be found that many of the hairs when pulled cause pain. This pain is not localised, but radiates widely. But, in addition, any movement, of these hairs, such as is produced by brushing the part lightly with cotton-wool, will cause a sensation differing from that over normal parts. For not only does it consist of a curious tingling, or formication, but it radiates widely and is frequently referred to parts at a distance. This sensation can be evoked only by stimulating the hairs, and, unlike the normal skin, the part becomes entirely insensitive to cotton-wool when shaved.

Whatever may be the stimulus that evokes a sensation from protopathic parts, that sensation is always characterised by a "tingling" quality and by defective localisation. So erroneous may be this localisation, that although the impact of the stimulating body is perceived and localised correctly,

the pain, or the cold, or the tickling of hairs, may be appreciated in some area far from the point of stimulation.

The return of sensation to light touch brings a gradual diminution in this tingling and widespread radiation so characteristic of protopathic sensibility.

Gradually the patient becomes able to distinguish two points of the compasses when separated to a distance more nearly approaching that at which they can be discriminated over the normal skin.

It might be urged that the gradual disappearance of radiation and defective localisation was due to the steady improvement of protopathic sensibility coincident with recovery of the nerve. On such a view, the word "protopathic" would be a convenient name for a stage in the recovery of sensation, but would have no further significance.

But everything seems to point to the introduction of a new factor rather than to the gradual improvement of a function already present. For, before the advent of light touch, the patient could appreciate correctly the point which had been pricked, or the area stimulated with ice, by means of the pressure so produced. But this did not hinder wide radiation of the specific sensation. This radiation is only brought to an end by the return of sensibility to light touch and the recovery of power to discriminate two compass points.

All power of localisation present before the return of light touch must have been due to what we have called deep sensibility. It is conceivable that the final disappearance of radiation and the other protopathic characteristics might be due to the development of a new quality that made localisation in the skin a possibility. This quality would be in some way associated with the return of sensibility to light touch. But this return could have no direct effect upon sensations of temperature, and yet one of the most definite features of this stage of recovery is the appreciation of intermediate degrees of temperature to which the part in the protopathic condition was insensitive.

Moreover, the return of sensibility to light touch seems so closely bound up with the recovery of sensation to inter-

mediate temperatures and with the discrimination of the compass points that we have united these three factors under the name of *epicritic* sensibility.

Whatever the specific nature of the sensations we have grouped under this name, they are all well localised and their reappearance within the affected area is accompanied by a coincidental decrease in radiation.

The use of these terms, "protopathic" and "epicritic," would be convenient even if they represented nothing but stages in recovery after division of a peripheral nerve. But we believe that each corresponds to the function of a distinct system of nerve fibres and end organs.

In a previous part of this paper (Chapter 1) we showed from a series of cases that the area rendered insensitive to light touch by division of the median or of the ulnar nerve varied little in extent.

In sharp contrast to this slight variation stood the extreme differences in extent of the loss of sensation to prick which followed division of either of these nerves. So greatly did the area of cutaneous analgesia vary in each individual instance that it was impossible to formulate any general statement concerning the normal extent of the area rendered insensitive to prick by division of the median or of the ulnar nerves. Moreover, the extent of the loss of sensation to light touch and to prick vary independently of one another. The most extensive cutaneous analgesia is not necessarily associated with an increased area of insensibility to light touch. Conversely, when the loss of sensation to prick occupies but a small extent of the hand, or is confined to the fingers, the area insensitive to light touch is not of necessity smaller in proportion. This want of relation between the extent of the loss of sensation to prick and to light touch after complete division of a nerve renders it unlikely that the two forms of sensibility are due to the same anatomical system of nerve fibres and end organs.

When the ends of a divided nerve have been successfully sutured, protopathic sensibility not only returns first, but the whole of the affected parts may remain for many months entirely insensitive to all the higher stimuli. If protopathic

and epicritic sensibility were only functional modifications in the activity of one anatomical system, it would be difficult to explain how the complete restoration of the one could leave entirely unaffected the extent of the area over which the other was absent. The improvement should be general, and should lead to a gradual retreat of the borders of the area insensitive to the higher stimuli step by step with the disappearance of the cutaneous analgesia. This actually occurs when a nerve has been injured and not completely divided. After such a lesion no widespread regeneration is necessary; the nerve fibres have but to recover their function temporarily in abeyance. But, after suture of a completely divided nerve, the two systems of fibres evidently regenerate with unequal facility, and thus the one form of sensibility is re-established before the other shows any signs of return. The results that follow the unaccompanied restoration of protopathic sensation have been fully described when we considered the condition of a part at the end of the first stage of recovery.

Protopathic sensibility is restored under conditions which materially hamper the return of the higher forms of sensibility. The formation of fibrous tissue between the two ends of a nerve greatly retards the restoration of sensation, but, when this fibrous tissue is removed at the operation for secondary suture, it sometimes happens that the extent of the protopathic loss is increased (Case 11, Case 28). This increase must have been due to the removal of nerve fibres intermingled with the fibrous tissue, which were capable of endowing the part with protopathic sensibility. Here a condition capable of preventing the return of the higher forms of sensation did not form an effectual bar to the regeneration of the fibres subserving protopathic sensibility.

With two systems of nerve fibres we should expect that occasionally injury of a peripheral nerve would produce the converse form of dissociated sensibility. On this hypothesis it is unlikely that the fibres would be distributed uniformly to every peripheral nerve, and we should find occasionally that a part insensitive to prick reacted to the lightest touch. Such a dissociation is rare, but seems to exist especially

after division of the posterior roots that supply the arm. In one such instance (Case 53, p. 196) we were able to show that an area in the region of the deltoid was insensitive to prick and to ice, but was sensitive, even after shaving, to cotton-wool and to the minor degrees of heat and cold. Here, too, sensation was good, although not perfect, when tested with the compasses.

The opportunity of testing an area of so considerable a size seldom arises, but in the case of one of us, after division of two nerves in the forearm, a triangular area insensitive to prick, but sensitive to light touch, made its appearance in the neighbourhood of the wrist. Here ice and water at 50° C. were not appreciated, but sensation seemed to be retained to temperatures between 36° C. and 45° C.

In Case 85, a small patch of dissociated sensation appeared on the back of the hand in consequence of division of the median and part of the radial and external cutaneous nerves at the wrist. Here the patient could appreciate stimulation with cotton-wool and with warmth, but was insensitive to prick and to the application of ice.

Thus, in conclusion, we believe that the following reasons render it probable that what we have called "protopathic" and "epicritic" sensibility depend on two anatomically separate systems of fibres and end organs.

Firstly, it is difficult to see how else can be explained the want of relation between the extent of the area rendered insensitive to light touch and that insensitive to prick after division of a peripheral nerve. Secondly, the comparatively early return of protopathic sensibility after suture of a completely divided nerve brings with it no diminution in the area insensitive to light touch and minor degrees of temperature. Whereas, if the nerve has been injured, but not completely divided, the two forms of sensibility return step by step. Thirdly, we have found on rare occasions that, after division of a peripheral nerve, a small portion of the insensitive area may react to stimulation with cotton-wool and to minor degrees of heat, but not to prick or to ice.

We have now reached the conclusion that every part of the limbs and surface of the body possesses three systems

of afferent fibres. The first of these runs with the motor nerves, and is not destroyed by the division of all cutaneous sensory branches. These afferent fibres supply the part with deep sensibility, and are responsible for much of the sensation that remains after division of peripheral nerves.

They run with the motor nerves from the periphery to the point where motor and sensory fibres separate, forming the anterior and posterior roots. Here they join the posterior roots and pass into the posterior columns of the spinal cord. In the case of the hand, we brought forward evidence to show that deep sensibility was materially diminished by division of the long tendons at the wrist. The afferent fibres upon which this sensibility depends must therefore have passed from the palm and fingers along the tendons; they then join in the forearm, the motor fibres to that muscle of which the tendon is only a prolongation. If we know the anterior root by which these motor fibres pass to innervate the muscle, we may assume that the equivalent posterior root will carry the afferent fibres connected with the tendon and its fibrous projection. Given the tendons and the aponeuroses which are necessary for the maintenance of deep sensibility to any part, we can then work out its segmental innervation.[1]

The observations detailed in this paper do not permit us to make any more definite statement with regard to the distribution of these afferent fibres concerned with deep sensibility. The question of the nature and extent of pain arising in connection with this system must be reserved for a future communication.

The laws which govern the two cutaneous systems can be laid down with greater certainty, at any rate as far as the limbs are concerned. In many ways the supply of epicritic sensibility is the simpler, especially from the peripheral aspect. We shall therefore begin with the epicritic supply of

[1] We have spoken throughout as if no fibres existed in the skin concerned with the conduction of pressure impulses. It must not be supposed that we do not believe such fibres exist. We are compelled to neglect them because these fibres are probably removed when all cutaneous sensory nerves have been divided. Since our only knowledge of the properties and distribution of deep sensibility can be gained from parts that have been deprived of all their cutaneous sensory nerves, any fibres concerned with deep sensibility existing in the skin are outside the limits of our method of observation.

the arm and hand; then we shall consider their protopathic innervation, and, finally, we shall apply the laws so established to the cutaneous nerves of the leg.

We have shown that the epicritic supply of the median and ulnar nerves overlaps little on the palm. When the ulnar is divided, the residual sensibility, maintained by the median, does not extend further on the palm than a line drawn through the axis of the ring finger; nor does it occupy more than two-thirds of that finger. In no instance has the median been capable of supplying epicritic sensibility to the whole of the ring finger after complete division of the ulnar nerve. Conversely, after division of the median, the radial half of the palm has in every case been insensitive up to a line drawn from the cleft between the middle and ring fingers. This boundary has a sinuous outline, but, roughly speaking, it corresponds to the vertical line just described. In no instance has the intact ulnar been able to innervate the whole of the ring finger after division of the median. These two nerves, as far as their epicritic supply is concerned, cannot overlap one another by the breadth of a single finger.

In the same way the border on the thenar eminence between the supply of the median and that of the combined pre-axial group of nerves (ramus cutaneus n. radialis and external cutaneous) is singularly constant and definite. After the median has been completely divided, the borders of the loss of sensation on the thumb and outer part of the thenar eminence correspond almost exactly to the radial boundary of the area that becomes insensitive to epicritic stimulation after destruction of the pre-axial group of nerves in the forearm.

Whenever the adjacent borders of two anæsthetic areas correspond closely in this manner, the two nerves by which they are supplied can overlap little as far as that particular form of sensibility is concerned.

On the back of the index and middle fingers the epicritic supply of the median, overlaps that of the pre-axial group by rather less than three-fourths of the extent of the basal phalanx.

On the dorsum of the hand, the epicritic boundary between the post-axial (ulnar and internal cutaneous) and the pre-axial group (ramus cutaneus n. radialis, external cutaneous and lower external cutaneous branch of the musculo-spiral) is formed by a line continuous with the axis of the ring finger.

In the forearm a sharp boundary separates the epicritic supply of the pre-axial from that of the post-axial group on both the flexor and extensor surfaces of the forearm. The branches of which the pre-axial group is composed overlap considerably, and destruction of any one of them leads to no well-defined area of anæsthesia to epicritic stimuli.

Thus, the epicritic supply of the nerves of the forearm and hand overlap little provided the anatomical branches are grouped as follows: (1) the ulnar and internal cutaneous, (2) the median, (3) the remainder of the pre-axial group.

Division of the branches forming any one of these groups will produce an area of epicritic insensibility, almost exactly corresponding to the extent of the residual sensation present when that nerve group alone remains intact. This correspondence between the extent of the area of epicritic anæsthesia and that of residual epicritic sensibility, shows that the supply of the nerve groups can overlap to no considerable extent.

But, when we examine lesions of trunks of the brachial plexus or of the posterior roots, these firm borders are no longer present. The remaining epicritic sensibility in the palm extends beyond the borders of either the median or ulnar nerve, and the area of epicritic insensibility is bounded by no definite borders.

Thus the supply of the epicritic system seems to be laid down in units that correspond in the upper limb with certain groups of anatomical nerves. Here lesions produce well-defined defects in sensation. The nearer we approach the posterior roots the less definite are the boundaries of the area insensitive to epicritic stimuli and the greater the overlapping of the injured cords or roots.

This was the conclusion to which Sherrington (12) arrived from experiments on monkeys. After determining by his

method of residual sensibility the amount of overlapping between the posterior roots that innervate the hand, he wished to see to what extent this overlapping was represented in the median and ulnar. "It is then clear," he says, "that in the hand . . . . of Macaeus the extent of overlap of the skin fields of the peripheral nerve trunks, even on the exquisitely sensitive . . . . palmar surface is much less than that of the cutaneous areas of the nerve roots; it is, in fact, not so great as may be the overlap of the fields of nerve roots three segments distant from one another."[1]

This complete accord between the results of our observations on man, and those made by Sherrington on monkeys, shows that the stimuli he used appealed to what we have called the epicritic system.

When we turn to the distribution of protopathic sensibility we come face to face with an arrangement fundamentally different. Division of the median or the ulnar nerve produces loss of protopathic sensibility over a comparatively small area with indefinite borders. The residual sensibility to protopathic stimuli present after the median nerve has been divided extends, in many instances, over the whole palm. After division of the ulnar the palm remains sensitive to such stimuli everywhere, except over the extreme ulnar border. Moreover, when the trunk of the ulnar nerve was irritated (Case 63, p. 316), the tenderness spread across the palm to the thumb and base of the index and middle fingers. The consequences of both division and irritation of these nerves show that, as far as protopathic sensibility is concerned, they overlap to an enormous extent.

The anatomical expression of this overlapping is found in the anastomotic branches which probably exist in order that the fibres subserving protopathic sensibility may pass from the territory of one nerve into that of the other.

On the back of the hand the ulnar and internal cutaneous extend as far as a line that corresponds roughly with the tendon of the middle finger. This post-axial group also

[1] *Phil. Trans. Roy. Soc.*, 1898, vol. cxc., p. 109. Compare also the figures on p. 108, which are wrongly numbered; the figure on the left of the reader is No. 2, that on the right No. 1.

supplies protopathic sensibility to the whole of the ring finger, except about one-third of the radial aspect of the terminal two phalanges; it also sends fibres to the ulnar half of the basal phalanx of the middle finger. The careful and laborious dissections of Brooks (3) and Hédon (6) bring out these points admirably, and show that the branches traced by them across the usual anatomical borders subserve the overlapping protopathic sensibility.

On the forearm division of the radial (ramus superficialis n. radialis) and external cutaneous produces an area of protopathic insensibility with a well-defined border on the flexor surface of the forearm. This border corresponds closely, except at the wrist, with that of epicritic loss; but at the wrist the protopathic fibres of the post- and pre-axial groups overlap greatly, and the loss of sensation to prick is less extensive than that to light touch.

Everywhere in the forearm and hand division of a peripheral nerve causes loss of protopathic sensation over an area of smaller extent than the accompanying epicritic insensibility; but, as soon as the nerve is injured on the central side of the brachial plexus, and especially if it be the roots that have suffered division, this rule may be reversed. The loss of protopathic sensibility exceeds in extent the area insensitive to epicritic stimuli, and the skin may be in parts sensitive to light touch, but not to prick (*vide* Case 52, p. 194).

The nearer the lesion is situated to the posterior roots the more extensive and definite is the loss of protopathic sensibility; the more nearly the injury divides one of the nerve groups described above, such as the median, the ulnar, or the pre-axial nerves, the more definite and extensive is the epicritic loss. It would seem, then, as if each of these peripheral nerves, or nerve groups, formed a unit of the epicritic system; the protopathic unit must be sought in one or more posterior nerve roots.

This does not imply that division of a single posterior root would produce an area insensitive to protopathic stimuli, but sensitive to light touch and to the minor degrees of heat and cold. For even from the protopathic aspect,

fibres of any two posterior roots overlap one another especially on the limbs. But this overlapping is considerably less for the protopathic fibres of any one posterior root than for those which subserve epicritic sensibility.

From this it follows that the area which becomes totally insensitive to protopathic stimulation after a peripheral nerve has been divided, represents the extent of skin supplied by those fibres of one or more posterior roots which run exclusively in that nerve. For instance, the area of total cutaneous insensibility which follows division of the ulnar, represents that part of the hand supplied solely by those protopathic fibres of the first dorsal root, which run in the trunk of that nerve. Every other part of the hand supplied by fibres that run in the first dorsal posterior root, will remain sensitive to protopathic stimuli because it is innervated also from the median.

If, then, it should happen that the area supplied by a peripheral nerve coincided with that of one or more posterior roots, division of that nerve would produce a patch of total cutaneous insensibility co-terminous for both epicritic and protopathic stimulation.

The external popliteal, including its lateral cutaneous branch, closely corresponds to such a nerve, excepting in the region of the knee and outer side of the foot. Complete division of this nerve produces an area of epicritic loss, bounded by a line which slants across the shin to a point just in front of the inner malleolus. In the region of the calf the boundary of the loss of this form of sensation runs vertically down the leg to the outer side of the tendo-Achillis.

Both these lines also form the boundaries of the loss of protopathic sensibility, so that here we find a remarkable coincidence of the borders of the loss to protopathic and epicritic stimuli, a condition foreshadowed by the consequences that follow division of the internal cutaneous in the forearm.

The relation of the other nerve branches in the leg is complex, and furnishes no clear example of the laws we have here laid down. The detailed discussion of their distribution will be found in Chapter 7.

It must not be supposed that we believe that each of these systems has one set of end organs only, and that each end organ is sensitive to every form of stimulus to which that system responds. In a subsequent paper it will be shown that, as far as protopathic sensibility is concerned, at least three end organs exist and each of these reacts only to a specific stimulus. In the present communication we are dealing only with the distribution of the fibres that underlie the two main forms of cutaneous sensibili ty.

In conclusion, we believe that the afferent fibres in the peripheral nerves can be divided into three systems.

(1) Those which subserve deep sensibility and conduct the impulses produced by pressure. The fibres of this system run mainly with the motor nerves, and are not destroyed by division of all the sensory nerves to the skin.

(2) Those which subserve protopathic sensibility. This system of fibres and end organs responds to painful cutaneous stimuli, and to the extremes of heat and cold. It also endows the hairs with the power of reacting to painful stimulation.

These fibres regenerate rapidly after the ends of the nerve have been reunited; if the operation has been successfully performed sensation begins to return within from seven to ten weeks.

In any peripheral nerve the distribution of the protopathic fibres usually overlaps greatly the area supplied by the fibres of the adjacent nerves.

(3) Those which subserve epicritic sensibility. The nerve fibres and end organs of this system endow the part with the power of responding to light touch with a well-localised sensation. The existence of this system enables us to discriminate two points and to appreciate the finer grades of temperature called cool and warm.

These fibres regenerate more slowly than those which subserve protopathic sensibility after reunion of a divided nerve, and sensation does not usually begin to return in less than six months under the most favourable conditions.

The distribution of these fibres in the larger peripheral

nerves, such as the median and ulnar, overlaps little compared with the great overlapping of the protopathic supply.

Appendix.

Case 4.—*Division of the median nerve.*

A. C., aged 20, cut his left wrist with glass on December 22, 1902. He was admitted to the London Hospital and seen by one of us five hours after the accident.

A transverse wound was present just above the wrist between the tendons of the flexor carpi radialis and the palmaris longus.

He was insensitive to all cutaneous stimuli over the darkened area shown in fig. 30, corresponding almost in extent with the area anæsthetic to cotton-wool and to the minor degrees of temperature.

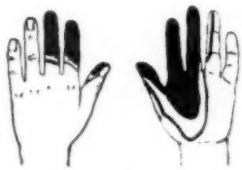


Fig. 30.

To show the extent of the loss of sensation in Case 4 produced by complete division of the median nerve.

The wound was explored an hour later, and the median nerve found to be divided; no other deep structure was severed. The wound was sutured, after the nerve had been united with a catgut stitch.

No diminution in the extent of the area insensitive to all cutaneous stimuli took place while he was in the hospital, and he was discharged on December 31, the wound having healed by first intention.

By February 4, 1903, the area of analgesia on the palm had begun to diminish in size, and on March 4, only the terminal two phalanges of the index and middle fingers and the palmar surface of the terminal phalanx of the thumb were insensitive to prick and to the more extreme degrees of heat and cold.

All analgesia had disappeared by July 17, but the area insensitive to cotton-wool and the intermediate degrees of temperature remained as extensive, and its borders were as well defined as on the day of the accident.

Until February 4, the hand and fingers were kept at rest and the nails grew unequally.

	Left (affected).	*Right.*
Thumb	0	5·5 mm.
Index	0	5·5 mm.
Middle	0	5·5 mm.
Ring	0	5 mm.
Little	0	5·5 mm.

He started work on June 3, and used both hands alike; the nails now grew to an equal extent on both hands.

	Left (affected).	*Right.*
Thumb	7 mm.	6 mm.
Index	6 mm.	6 mm.
Middle	6 mm.	6 mm.
Ring	6 mm.	6 mm.
Little	6 mm.	6 mm.

By September 6, he could appreciate light touch and water at 22° C. and at 40° C. over the proximal portion of the affected half of the palm; over these parts the compass test was good at 2 cm.

On September 30, the opponens and abductor muscles acted voluntarily and reacted to the interrupted current. Cotton-wool and the minor degrees of temperature were appreciated over the whole affected palm on this date, but the fingers remained anæsthetic until November 18.

A marked line of change to prick was present, bounding the old anæsthetic area until June, 1905. By August 21, 1905, this had disappeared, and the compass test was perfect at 1 cm.

Case 6.—*Division of the median nerve. Recovery thrown back by the formation of an abscess at the site of the healed wound. Trophic disturbances of the skin.*

S. H., a barber, aged 21, cut his right wrist with a razor on October 3, 1903. The wound was explored the following day; the median nerve, the tendons of the flexor sublimis digitorum, flexor longus pollicis, and several of those of the flexor profundus, were found to have been divided. The nerve was sutured with silk, the tendons with catgut.

On January 13, 1904, when he first came under our observation, the outer group of thenar muscles was markedly wasted, but contracted voluntarily and reacted to a strong interrupted current.

The skin of the median half of the affected palm was dry and harsh, contrasting in a marked manner with the smooth, moist appearance of the unaffected portion. On the radial side of the tips of the index and middle fingers were blisters; these he had noticed on waking three mornings previously. They had not been present when he went to bed, and were caused by no known injury.

He was insensitive to stimulation with cotton-wool, and the minor degrees of temperature over the area shown in fig. 31. Over the terminal two phalanges of the index and middle fingers, the palmar surface of the terminal phalanx of the thumb, and the extreme radial border of the last two phalanges of the ring finger, he failed to appreciate a prick, ice, water at 60° C., and pressure.

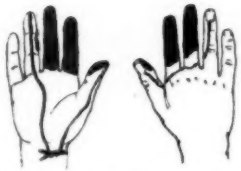


FIG. 31.

To show the extent of the loss of sensation in Case 6.

On March 30, 1904, we noticed the first sign of recovery; the area insensitive to prick and to the extremes of heat and cold had diminished in size on the index and middle fingers, and had entirely disappeared from the thumb and ring finger. Up to this date, numerous blisters had appeared on the analgesic portions of the index and middle fingers. Some had dried, leaving a mass of thickened epithelium; others had formed shallow ulcers. On March 30, for the first time, the skin was free from any lesion of this character.

By April 27, 1904, all analgesia had disappeared, and wate at 60° C. and ice were everywhere appreciated.

The hand remained in this condition, sensitive to prick, but anæsthetic to cotton-wool, until August 10, 1904. The borders of the anæsthetic area were well defined, and within it he failed entirely to discriminate the two points of a pair of compasses separated for a distance of 2 cm.

Shortly after this visit, an abscess appeared at the scar; it had been opened and had healed when we next saw him on

September 21, 1904. We then found that a change had taken place in the condition of his sensibility. He no longer appreciated a prick and the extremes of heat and cold over the same area, that was insensitive to these stimuli, when we first saw him eleven months before.

On October 23, 1904, he discovered a blister on the terminal phalanx of the middle finger. When we saw him next, four days later, it had broken, and a superficial ulcer marked its site. Sensibility to prick was still lost over the original area, but he occasionally appreciated ice, and water at 50° C.

From this time onward, blisters made their appearance at intervals, usually without any history of injury, and when we saw him on March 30, 1905, the terminal phalanges of index and middle fingers were still analgesic, and ulcers were present. By July 8, these had healed, and the appearance of the skin approached the normal; all analgesia had disappeared.

He still showed a definite line of change to prick on the palm, and within the boundaries of this line he was now sensitive to stimulation with cotton-wool, and the intermediate degrees of temperature. But within this area, he was unable to discriminate two points at a distance of 3 cm.

Case 29.—Injury to the median nerve, produced by a cut at the wrist. Simultaneous return of the two forms of cutaneous sensibility.

On September 20, 1902, whilst loading a van, C. B., aged 27, slipped and cut his left wrist on a broken bottle. He came to the London Hospital at once, and was seen by us, one and a half hours after the accident. He complained of "pins and needles" and "numbness" of the thumb, index, and middle fingers, which had been present since the injury. The wound was oblique, running from the tendon of the flexor carpi radialis, close to the fold of the wrist, upwards and ulnarwards for a distance of 1½ ins. (4 cm.).

The opponens and abductor muscles of the thumb were acting well. He was unable to appreciate light touch over the full median area on the palm and fingers. Sensation to prick and to the extremes of temperature was abolished over the palmar surface of the index and middle fingers and over an area on the palm at their base (*vide* fig. 32). Over the dorsal surface of the two terminal phalanges of the middle finger, the ulnar half of the terminal phalanx of the index and the extreme radial border of the ring fingers, sensibility to prick was also destroyed.

The wound was explored one hour later by one of us, and the

median nerve was found to have been injured; it was swollen, and had been cut into on its ulnar side. The tendon of the flexor sublimis digitorum going to the index finger was also divided. After suture of the tendon, the wound was closed and healed by first intention.

On October 22, analgesia was present over the index and middle fingers only, and he was able to appreciate light touch over the proximal part of the palm, both forms of sensation returning together in the manner usual after incomplete division of a nerve. The abductor and opponens pollicis muscles were wasted, but acted readily; they did not react to the interrupted, but reacted normally to the constant current.

By February 11, 1903, he could appreciate a prick everywhere, except over the terminal phalanx of the index and middle fingers;

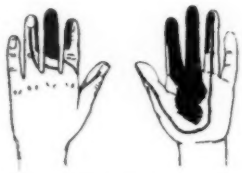


FIG. 32.

To show the extent of the loss of sensation in Case 29.

light touch was only lost over these two fingers and the palmar surface of the thumb. All the muscles reacted perfectly to the interrupted current and were no longer wasted.

On July 12, the last occasion on which we saw him, he was able to appreciate a prick everywhere, but the last two phalanges of the index and middle fingers and the palmar surface of the thumb were still insensitive to light touch and the minor degrees of temperature. To the compass test at 2 cm., he showed the phenomenon of "double ones" to perfection.

Case 82.—*Division of the median nerve. Improvement after five years.*

J. R., a youth of 16, cut his left wrist with glass on February 20, 1897. He was admitted to the London Hospital the same day, and the median nerve was sutured. The wound suppurated and did not finally heal for over four months.

He first came under our observation on January 29, 1902,

complaining that "numbness" was still present in the index and middle fingers.

The whole of the affected hand was of a bluish colour, and seemed undoubtedly colder to the touch than the sound hand. The outer thenar group of muscles was slightly wasted, but was acting feebly, and reacted to a strong interrupted current.

The last two phalanges of the index and middle fingers on their dorsal and palmar aspects were insensitive to prick, to ice, and to water at 50° C. Over the usual median area on the palm and the extreme radial border of the ring finger, light touch, the minor degrees of temperature and the interrupted current, applied with no iron in the circuit, were unappreciated. Within this area, he failed to distinguish the points of the compasses, even when separated to a distance of 3 cm.

By August 24, considerable improvement had taken place. There was now no change in the appearance of the skin, all muscular wasting had disappeared, and the contraction evoked by the interrupted current was normal. Analgesia was present only over the terminal phalanx of the middle finger on its palmar aspect. Light touch and the minor degrees of temperature were appreciated over the palm of the hand. Marked improvement had taken place in his ability to distinguish the compass points; he was now perfect at 2 cm., and his answers at 1·5 cm. were good.

By November 16, all analgesia had disappeared, and he could appreciate light touch and the minor degrees of temperature over the whole of the affected parts. This area was bounded by a line of change to prick presenting the usual characteristics; no further improvement had taken place in his ability to appreciate the compass test.

When we last saw him, on January 25, 1903, the condition of the hand remained the same; the blueness and coldness which were present when he first came under observation had disappeared, and had not returned with the advent of winter.

Case 11.—*Division of the median nerve. Trophic changes consisting of blisters, ulcers, and necrosis of the terminal phalanx of the middle finger.*

D. J. T., a stonemason, cut his right wrist with glass in May, 1901. The wound was sutured at once without an anæsthetic.

He first came under our observation on November 27, 1901. An oblique scar ran upwards towards the ulnar side across the

lower third of the forearm, from the tendon of the flexor carpi radialis almost to the flexor carpi ulnaris.

The index and middle fingers were the seat of ulcers which had developed as the consequence of infection of what he called "water blisters." On the radial side of the distal phalanx of the index finger, distinct loss of tissue had been produced by a small deep ulcer with indurated edges. On the palmar surface of the same finger were two superficial ulcers, surrounded by a fringe of skin representing the blister from which they had originated. A small blister was present on the dorsum of the second phalanx of the middle finger.

The outer part of the thenar eminence was wasted, and the abductor, and opponens pollicis were not acting; these muscles did not react to the interrupted current and reacted in a typically sluggish manner to galvanic stimulation.

Light touch was lost over the median half of the palm; the palmar surface of the thumb, index and middle fingers, and the radial border of the ring finger, were insensitive to this form of stimulation. The last two phalanges of the index and nearly the whole of the last two phalanges of the middle finger were analgesic.

He remained at his work until May, 1902. During this time the "trophic" changes in his fingers became more pronounced. On April 6, 1902, the last two phalanges of the index and middle fingers were enlarged and the skin thickened. The tip of the index finger was occupied by an ulcer; its nail was represented by a rough, irregular mass. The nail of the middle finger had been cut away to expose an ulcer occupying the tip of the finger, and the nail-bed.

The area of loss of sensation to light touch and to prick remained unchanged on May 14. Two days later, Mr. Eve exposed the nerve and found that it had been completely divided; the ends were lying about 3 cm. apart, united by fibrous tissue. They were freshened and reunited, and the wound healed by first intention (*vide* fig. 3, B, p. 136).

During his stay in the Hospital, the ulcers on the index and middle fingers healed, and the skin regained its normal appearance. He started work again during the last week in July, and a week later a "blood blister" appeared on the tip of the middle finger. By August 6 this had become a shallow ulcer surrounded by thickened epithelium, and on the radial side of the finger was another small dry blood blister. He remained at his work, and the condition of the middle finger became worse; necrosis of the terminal phalanx supervened, necessitating amputation through the second phalanx on November 4.

On December 21 the area of analgesia had become smaller. The general nutrition of the fingers had improved, but there were still small ulcers on the index and middle fingers within the analgesic area.

By January 25, 1903, a prick, ice, and water at 40° C., could be appreciated everywhere within the affected area. All the ulcers had healed, and no further trophic changes made their appearance, although he continued his work as a stonemason.

The opponens pollicis acted voluntarily and responded to a strong interrupted current on May 24, 1903.

The hand remained sensitive to prick and the extremes of temperature, but insensitive to light touch, and water at 22° C. and 38° C., until January 31, 1904. On this date, the borders of the anæsthetic area were as well defined as immediately after suture.

When we again saw him on April 10, he could appreciate light touch and the minor degrees of temperature everywhere over the affected hand. A marked line of change to prick was present, and two points were badly discriminated at 2 cm. He remained in this condition, until we finally lost sight of him in March, 1905.

Case 64.—*Incomplete division of the median nerve. Recovery of the two forms of sensibility* pari passu. *Trophic changes of the nails.*

G. L., aged 13, cut his right wrist with glass in August, 1901. The wound was stitched without an anæsthetic, and the condition of the median nerve was not explored.

He came under our observation on November 4, 1901, complaining of "sore nails."

Ever since the accident he had noticed numbness of the hand, and for a month the nails had been "sore." Three weeks before we saw him, the nails of the index and middle fingers "came off."

A transverse scar was present over the situation of the median nerve, 2·5 cm. above the fold of the wrist. The outer group of thenar muscles was wasted, but acted voluntarily and responded to stimulation with the interrupted current. The terminal phalanges of the index and middle fingers were bulbous, the nails had been shed, and the nail-beds had become ulcers with protuberant granulations forming their floor. The nails of the thumb, ring, and little fingers showed no obvious abnormality.

Cotton-wool, the interrupted current generated without iron in the circuit, and the minor degrees of temperature, were unappreciated over the full median area. Sensibility to prick was

lost over the terminal two phalanges of the index and middle fingers. He entirely failed to discriminate two points when separated for a distance of 2 cm.; on a similar portion of the sound palm he made no mistakes at 1 cm.

By February 26, 1902, the area of loss to cotton-wool, the interrupted current, and the minor degrees of temperature, had retreated to the fingers, but the terminal phalanges of the index and middle fingers were still insensitive to prick. He had improved markedly to the compass test, and could discriminate the two points at 2 cm. correctly over the affected palm. The nails had begun to grow, and the nail-beds were no longer ulcerated.

All analgesia had disappeared on April 16, 1902, but he was still insensitive to stimulation with cotton-wool and to the minor degrees of temperature over the last two phalanges of index and middle fingers. A well-marked line of change to prick was present on the palm and on the dorsal surface of the index and middle fingers, bounding the old area anæsthetic to cotton-wool. Within this area he appreciated two points separated to a distance of 1·5 cm. After this date he changed his address and we were unable to see him again.

Case 33.—*Injury to the forearm; Volkmann's contracture. Implication of the median nerve in scar tissue.*

H. E. T., aged 20, fell while playing football on December 26, 1903, and injured his left arm. He was taken at once to an infirmary and his forearm put up in internal and external splints. When these were removed a week later, "a long black bruise" was found over the anterior (flexor) surface of the forearm and a smaller one on the dorsal surface near the wrist. Soon "the bruise began to take a bad turn," the skin broke, and an ulcer appeared, which did not heal for over three months. Fourteen days after the accident "the arm was rebroken and set in a special splint so that the ulcer could be dressed." His forearm remained in splints for three months, and when these were removed, he noticed that the fingers were numb and becoming bent.

When he came under our observation on July 2, 1904, an adherent scar marked the site of the ulcer on the anterior surface of the forearm; over the lower end of the radius, a scar marked the site of the smaller ulcer which had been present there. All the movements of his forearm were free, excepting supination, which was slightly limited. The seat of the fracture was marked by no bony thickening or deformity.

The hand was held a little flexed at the wrist, with the fingers and thumb slightly flexed into the palm. On extension of the wrist, the fingers could not be brought into line with the palm, but when the wrist was flexed they could be almost fully extended. He thus showed the signs of Volkmann's contracture in a slight degree.

The fingers of the affected hand were tapering, and the skin of the palm and fingers smooth, that of the latter being of a reddish-blue colour. A blister, for which he could not account, was present on the palmar surface of the terminal phalanx of the index finger. All the nails of the affected hand "were growing more slowly" than those on the sound side, and showed marked transverse ridges.

The intrinsic muscles of the hand were wasted, but acted voluntarily and reacted to the interrupted current, with the exception of the abductor and opponens pollicis.

He was insensitive to all forms of cutaneous stimulation over the last two phalanges of the index and middle fingers. Light touch and the minor degrees of temperature were not appreciated over the full median area; this was well defined, except at its proximal border. Over the distal portion of the affected part of the palm, he failed to discriminate two points separated for a distance of 3 cm., but over the proximal portion, the formula yielded at this distance was good ($\frac{1|6\,R.\,4\,W.}{2|7\,R.\,3\,W.}$). Deep touch and the vibrations of a tuning-fork (C 128) were recognised over the whole of that portion of the hand which was analgesic.

We next saw him on July 24, 1904. During the three weeks that had elapsed, he had received no treatment of any kind, and the nails of the affected hand had grown more slowly than those on the sound side.

	Left (affected).	*Right.*
Thumb	3 mm.	4 mm.
Index	3 mm.	4 mm.
Middle	2·5 mm.	4 mm.
Ring	3 mm.	4 mm.
Little	3 mm.	4 mm.

The appearance of the hand remained the same, but all the muscles now responded to the interrupted current and the outer thenar group reacted to the constant current at 2 ma. with a brisk contraction, K.C.C. appearing before A.C.C.

On August 11, Mr. Dean explored the median nerve in the

forearm. The fibrous tissue composing the scar passed deeply, and was adherent to the periosteum of the ulna. In this mass the median nerve was embedded; it was freed and the wound closed. Healing took place by first intention.

The first effect of the operation was to throw back the sensory and motor condition of the hand. The loss of prick became as extensive as when we first saw him, and the abductor and opponens muscles lost their reaction to the interrupted current. No improvement took place for about two months; then both forms of sensation began to return together, and by the end of November, 1904, were only lost over the index and middle fingers. All analgesia had disappeared by February 26, 1905, leaving the terminal phalanges of the index and middle fingers still insensitive to light touch and the minor degrees of temperature. By this date the abductor and opponens muscles had regained their reaction to the interrupted current.

As the result of regular massage, the contracted condition of his fingers had improved considerably and was hardly noticeable on August 27, 1905. At this time he could appreciate light touch and the minor degrees of temperature everywhere, and was perfect to the compass test at 1·5 cm.

Case 19.—*To show the effect of surgical division of the ulnar nerve at the elbow upon deep sensibility and cutaneous sensation of the hand.*

L. C., a tailor, aged 36, came under our care on June 8, 1904. He complained of weakness of the hand, and of pain in the ulnar side, especially troublesome while at work. These symptoms had been present for seven months, and were increasing in severity.

He was unable to appreciate light touch over the full extent of the ulnar area (fig. 33). He could appreciate a prick everywhere, but ice, and water at 50° C. were only recognised over the proximal portion of the palm.

The hand was in the typical ulnar position; all the muscles in the forearm and hand supplied by the ulnar nerve were paralysed and markedly wasted. They did not react to the interrupted current, but responded to galvanic stimulation with a sluggish contraction.

Pronounced changes were present in the lower end of the humerus. The carrying angle of the forearm was much diminished and the internal condyle enlarged and irregular. A swelling was present on the ulnar nerve where it passed between the olecranon and internal condyle, but the nerve could not be displaced. The

movement in the elbow-joint was surprisingly good, supination alone being slightly limited. He was not aware of the deformity, and no history could be obtained of any injury during childhood.

From our examination we concluded that the original injury had been a separation of the lower epiphysis of the humerus in early life. It seemed probable that the nerve had been injured as the result of long-continued pressure from the deformed internal condyle. In accordance with this diagnosis, the ulnar nerve was exposed by one of us at the elbow on June 17, 1904. In this situation about $1\frac{1}{2}$ ins. (4 cm.) of the nerve was hard, fibrous,

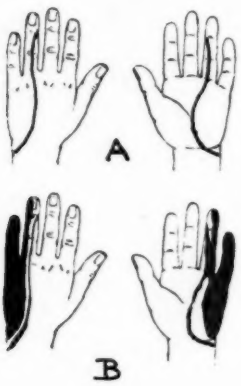


FIG. 33.

To illustrate Case 19.

A shows the area of insensibility to light touch and to the intermediate degrees of heat and cold present before the operation.

B shows the loss of sensation which followed division and reunion of the divided ends of the ulnar at the elbow.

and swollen; $1\frac{3}{4}$ ins. (4·5 cm.) of the nerve, including the swelling, was removed, after a groove had been made in the bone to prevent the recurrence of the pressure; the ends of the nerve were then sutured. The wound healed by first intention.

This operation did not increase the area within which he was unable to appreciate light touch, but the extent of the area insensitive to prick was greatly enlarged (fig. 33, B). Deep touch, tested with the head of pin, could not be appreciated over an area a little smaller in all directions than that for loss of prick.

The vibrations of a tuning-fork (C 128) evoked no sensation over the little finger.

By September 14 the analgesic area had diminished considerably in size, and on December 21 occupied the little finger only. Deep touch and the vibrations of a tuning-fork (C 128) were recognised everywhere by May 17, 1905. On August 16, all analgesia had disappeared, and ice could be appreciated over the whole affected area, but he was unable to recognise water at 50° C. over the little finger. The borders of the area insensitive to light touch remained as definite as immediately after section of the nerve.

Case 83.—*Excision of a portion of the ulnar nerve in the forearm.*

In August, 1899, Ernest C., aged 27, cut his wrist severely as he was opening a window. The wound was not stitched, but it healed in a week. About ten days after the accident, pain of a

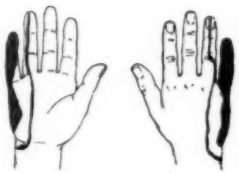


FIG. 34.

To show the loss of sensation produced in Case 83 by excision of a portion of the ulnar nerve in the forearm.

neuralgic character started in the scar, and at last became so troublesome, that in October, 1899, the wound was explored in St. Thomas's Hospital. As the pain did not decrease, he again entered the Hospital on November 30, and on December 21, the ulnar nerve was stretched at the wrist. In February, 1900, the nerve was again explored and freed from cicatricial tissue. As the pain was not materially relieved by these operations, he entered Guy's Hospital in November, 1900. Here the nerve was first stretched, then divided, and, finally, on two separate occasions, a considerable portion was removed in the forearm.

We saw him first on November 20, 1901; at that time the whole hand was wasted, except the muscles over the outer part

of the thenar eminence. The fingers were maintained in the position typical of ulnar paralysis. The little finger was blue and cold, and the nails of all the fingers were curved in both directions.

He complained of pain starting over the metacarpal bone of the little finger and travelling along the ulnar side of the hand to the scar on the ulnar aspect of the forearm. This pain he described as neuralgic and shooting in character, not constantly present, and ceasing for forty-eight hours at a time. It was worse in cold weather, and could be started by pressure upon the scar.

Deep touch was lost over the terminal two phalanges of the little finger and over a small area on the ulnar border of the hand. All other forms of sensation were absent over the darkly shaded portion in fig. 34. Cotton-wool was not appreciated over the area enclosed within a single line, and these parts were also insensitive to the interrupted current produced without iron in the circuit and to intermediate degrees of heat and cold. Localisation was extremely defective over the intermediate zone that lay between the border of loss to light touch and that of complete analgesia. Within this zone, the patient was unduly sensitive to all painful stimuli.

The whole of the intrinsic muscles of the hand, excepting the abductor and opponens pollicis, were paralysed, and did not react to the interrupted current. They were so profoundly wasted that we were in doubt whether any reaction was present to the constant current.

Case 34.—*Partial division of the ulnar nerve. Rapid return of both forms of sensibility.*

C. T., aged 28, put his left hand through a glass window on March 4, 1905, cutting the wrist. He immediately felt "pins and needles" in all the fingers of the affected hand.

He came to the London Hospital and the wound was explored four hours after the accident. The ulnar nerve was found to have been cut into below the point where the dorsal branch was given off, and the tendon of the flexor carpi ulnaris had been completely divided. Both nerve and tendon were sutured.

When we saw him on April 8, the wound had healed by first intention, leaving an oblique scar, running from the extreme ulnar border of the wrist upwards and radialwards. The hand was in the position characteristic of ulnar paralysis, and none of its muscles supplied by the ulnar nerve were acting with the exception of the first dorsal interosseous. Stimulation with an

interrupted current failed to elicit any contraction from these muscles.

Sensibility to light touch and to the intermediate degrees of temperature was lost over the area usually insensitive to these stimuli after division of the ulnar nerve below its dorsal branch. He was unable to appreciate a prick and the more extreme degrees of temperature over the palmar surface of the little finger.

By June 17 the wasting of muscles had almost disappeared, but the hand still retained its abnormal position; all the muscles were acting and responded normally to stimulation with the interrupted and with the constant currents. The analgesia had retreated to the terminal phalanx of the little finger on its palmar aspect, and he could appreciate touches with cotton-wool over the dorsal surface of the little finger, the area on the palm remaining as definite as when we first saw him.

On August 26, cotton-wool, and water at 24° C. and at 34° C. could be appreciated everywhere within the affected area; but a line of change to prick marked out the old anæsthetic border on the palm and on the dorsum of the fingers. Over the palm to the ulnar side of this line the compass test gave the following results: 2 cm. $\frac{1 \mid 7 \text{ R. } 3 \text{ W.}}{2 \mid 7 \text{ R. } 3 \text{ W.}}$, 1 cm. $\frac{1 \mid 4 \text{ R. } 6 \text{ W.}}{2 \mid 5 \text{ R. } 5 \text{ W.}}$ Over a similar portion of the sound hand no mistakes were made with the points 1 cm. apart.

On May 6, 1905, all muscular wasting had disappeared, and all the intrinsic muscles of the hand were acting well, but the little finger still remained a little abducted and extended at the metacarpo-phalangeal joint.

The hand was sensitive to all stimuli, but the line of change to prick was still present, and he showed no further improvement to the compass test.

Case 24.—*Division of the ulnar nerve below its dorsal branch. Complete separation of the ends for a year and four months. Degradation of sensibility in cold weather.*

Edith A., a girl of 17, cut her right wrist with a fragment of a broken bottle on March 7, 1902. The wound was explored and the two ends of the tendon of the divided flexor carpi ulnaris were said to have been sutured; the condition of the ulnar nerve was not investigated. The wound healed by first intention.

She came under our observation on May 28, 1902, complaining of numbness of the ulnar side of the palm and inability to straighten her fingers. She was an anæmic girl with well-marked signs of congenital syphilis.

A semilunar scar was present, 4 cm. above the fold of the left wrist, running with its convexity downwards from the inner side of the tendon of the flexor carpi ulnaris to the palmaris longus. The hand was held in the position typical of ulnar paralysis; the inner group of thenar muscles and the interosseous spaces were wasted, and all the intrinsic muscles of the hand supplied by the ulnar nerve were paralysed and failed to respond to the interrupted current.

She was unable to appreciate light touch over the area in fig. 35; the radial boundary of this area was well defined, but that

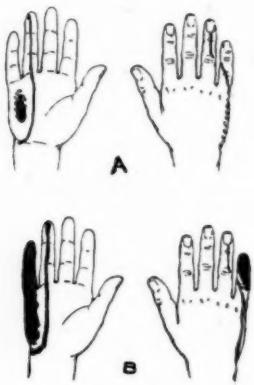


FIG. 35.

To illustrate Case 24.

A shows the area of loss of sensation present when the patient first came under our notice in May, 1902.

B shows the loss of sensation which preceded and followed the operation in July, 1903.

on its ulnar side merged gradually into the normal sensibility of the dorsum of the hand. Within this area of loss of light touch on the palm was a small oval area where she was insensitive to prick. Ice, and water at 60° C. were recognised except over the palmar surface of the little finger and within the area of loss of sensation to prick. She failed to discriminate the two points of the compasses within the area insensitive to light touch, but sensitive to prick, when the points were separated for a distance of 2 cm. On the similar portion of the sound hand, no mistakes were made at 1 cm.

When we next saw her, on July 11, sensibility to prick was everywhere present, and ice, and water at 60° C. were well recognised over the whole affected area. From this time, her power to appreciate temperature deteriorated; on August 8, water at 60° C. was nowhere recognised, and ice was only appreciated on the palm, when the test tube was laid longitudinally and allowed to remain in contact with the skin for some seconds. By November 14, ice was only appreciated over the proximal portion of the palm, although a prick was readily recognised everywhere.

The hand remained in this condition until March 9, 1903. On this date, marked diminution in her power of appreciating prick was noticed, and by May 13 the area of analgesia almost corresponded with the area of loss of light touch. Thus it remained until July, varying, within small limits, from time to time (fig. 35, B).

On July 22, 1903, the condition of the nerve was explored by one of us. It was found to be divided below the point where its dorsal branch is given off, and a remarkable condition was present, effectually preventing all chance of union between its two ends. On tracing the upper portion of the nerve downwards, it was seen to bifurcate; its inner portion had been united to the upper end of the divided tendon of the flexor carpi ulnaris, its outer to the lower end of the same tendon. The lower end of the nerve had been sutured to the divided tendon of the flexor sublimis going to the little finger. The nerve was reunited after its ends had been freshened.

This operation produced no alteration in the distribution or extent of the loss of sensation. On January 14, 1904, all analgesia had disappeared, but she failed to recognise ice over an oval area on the palm, corresponding to that present when we saw her first. Water at 60° C. produced no sensation of warmth over an area almost as extensive as that of the loss of light touch. She could appreciate ice everywhere on March 30, but even on this date water at 60° C. produced no sensation of warmth over the whole affected area, and it was not until June 21 that she was able to recognise this form of stimulation.

Sensibility to light touch began to return over the proximal portion of the palm on March 30, 1904, and by June 27 was lost only over the little finger. It had completely returned by September 21, leaving a well-marked line of change to prick. But on this date water at 40° C. and at 20° C. failed to evoke any sensation of temperature within the line of change, and it was not until May 31, 1905, that these minor degrees were recognised.

On August 16, 1905, the line of change to prick was still present. The compass test was perfect at 2 cm., poor at 1·5 cm. and at 1 cm. out of ten stimulations with two points, a correct answer was given on two occasions only.

On July 27, 1904, the first dorsal interosseous muscle responded to the interrupted current, and acted voluntarily. She is now (August 1905) able to contract all the affected muscles feebly.

Case 63.—*Bullet wound of the ulnar nerve in the forearm. Partial loss of sensation over the ulnar area. Widespread hyperalgesia. Resection and reunion of the two ends of the nerve. Disappearance of all hyperalgesia.*

On July 22, 1901, L. G. H., aged 26, was wounded at Tweefontein; the bullet ricocheted from the butt of his rifle and entered his forearm on the ulnar side in front of the bone, 4½ ins. (11·5 cm.) below the inner condyle of the humerus. It passed across the arm, and was extracted from the radial side eight hours later. When hit, he was retiring with his rifle "at the trail," and it fell from his hand. A severe tingling sensation appeared at once, and he could neither open nor close his hand. After he had been in hospital three weeks, his hand became more painful, and about four weeks after the injury, the excessive sweating and the change in the appearance of the hand was first noticed. During the last two months of 1901, the pain steadily increased; it was worse in a warm room, but if he could keep his hand in either hot or cold water, the throbbing pain ceased. The pain did not keep him awake at night, and never extended higher in the forearm than the wound. The nails began to grow faster than on the sound hand, and that of the little finger grew faster than any other.

Owing to the kindness of Professor Barker, we were permitted to see this man in University College Hospital on January 26, 1902.

He lay in bed with his arm raised, with the radial side of his hand resting on the pillow, so that nothing was in contact with the ulnar half. He was in evident distress, and anxious lest his hand should be touched.

The radial palm and palmar aspect of the thumb, index, and middle fingers were covered with heavy beads of sweat such as is rarely seen upon the hand, even in a Turkish bath, and the skin over these parts had a soft, sodden feeling, as if from

fomentations. The ulnar half of the palm and the palmar aspect of the little finger were dry. The whole hand on the palmar surface was smooth and of a pinkish-blue colour; markings were not absent, but they were less numerous and less deep than on the normal hand. On the dorsum the skin was but little affected, but over the dorsal surface of the fingers, particularly over the last two phalanges, the skin was thin and shiny. All the fingers and the thumb tapered from the base upwards, whereas on the

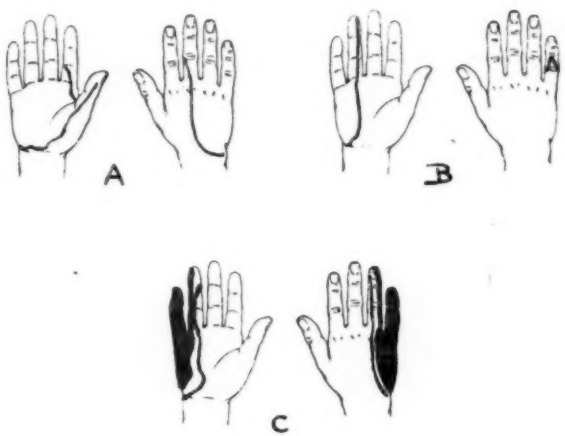


FIG. 36.

To illustrate Case 63.

A shows the extent of the loss of sensation to light touch when the patient first came under our observation.

B shows the area which was intensely hyperalgesic to all cutaneous stimuli causing pain.

C shows the extent of the loss of sensation after excision of a portion of the ulnar nerve and reunion of the divided ends by means of a graft.

sound hand they were more spatulate in form. The nails were curved horizontally and longitudinally, and those of the little, ring, and middle fingers were so painful and tender that he dared not cut them.

He complained of spontaneous throbbing pain mostly in the little, middle, and ring fingers; occasionally the pain invaded the index finger, and it was almost always present over the palmar

aspect of the terminal phalanx of the thumb. This pain never extended above the wrist, and did not affect the dorsum of the hand.

He was insensitive to cotton-wool over the ulnar half of the hand, over the little finger, and over the ulnar half of the ring finger (fig. 36, A). The interrupted current, generated without iron in the circuit, was not appreciated over the same area. When 1·5 cm. apart, the two points of the compasses were wrongly appreciated eight times out of ten over the ulnar half of the palm. Over the radial half of the affected hand and over the ulnar half of the normal hand, they were not only perfect at this distance, but were recognised without mistakes when 1 cm. apart.

The whole of the palm of the hand was profoundly hyperalgesic, and if the point of a pin was dragged lightly from the radial side of the thenar eminence towards the ulnar half of the palm he cried out at once that it caused excessive pain when the border marked in fig. 36, B, was passed.

Within the area included by this line, picking up the skin or stimulation with the blunt head of a pin caused intense pain. The borders of this hyperalgesia were difficult to define on the dorsum of the hand, but it seemed to occupy the ulnar half and the whole dorsal surface of the little, middle, and ring fingers. The index finger was not affected, excepting at its extreme base on the ulnar side. Ice, and water at 55° C. were correctly appreciated everywhere. No part of the hand was insensitive to pressure, and within the hyperalgesic area it was uniformly disagreeable.

All the interosseous spaces were profoundly wasted; the muscles of the thenar eminence supplied by the median were unaffected, and he could abduct and oppose the thumb normally. Abduction and adduction of the fingers were impossible; they were out of alignment, and the ulnar two lumbricales were not acting. The thenar muscles supplied by the median nerve reacted well to the interrupted current; but he could stand no current sufficiently strong to test the reaction of the interossei.

On January 30, 1902, Professor Barker exposed the ulnar nerve. The lower end was easily found and was traced up into a mass of firm fibrous tissue where it disappeared; the upper end was lost in the same dense tissue. The two ends were at least 1 cm. apart, and were not in the same direct line. The bullet had apparently injured the nerve in its passage across the limb, and its track was represented by the dense fibrous tissue in which

ended both the upper and the lower portions of the nerve; 1 cm. was removed from the upper portion, and the lower end was divided at different levels until healthy nerve fibres were reached. After the track of the nerve had been cleared from fibrous tissue, the two ends were so widely separated, that it was determined to fill the gap with the sciatic nerve of a freshly killed cat. To 5 cm. of this nerve the upper and the lower ends of the ulnar nerve were sutured by means of linen thread, and the forearm was bandaged to a splint with the hand midway between flexion and extension.

He was kept under morphia until the morning after the operation. When he recovered consciousness, he suffered from a good deal of pain in the wound, but all pain and tenderness had left the hand. On February 2, he would permit the hand to be manipulated, and pressure or picking up the skin failed to produce any discomfort.

The whole of the ulnar half of the hand was totally analgesic, the loss of sensation to prick and to the extremes of temperature extending over the ulnar half of the ring finger. The area over which light touch was lost almost exactly coincided with that of loss of sensation to prick (*vide* fig. 36, c).

On March 7, the condition of the hand was that described above, except that the loss of sensation to prick and to the extremes of heat and cold did not extend quite so far towards the radial side; thus there was now a zone of 1·5 cm. in breadth which was sensitive to prick, but insensitive to light touch. By September 3, this had increased considerably. Over this intermediate zone not only was light touch lost, but water at 20° C. and at 40° C. were not appreciated; sensation to prick, to water at 45° C., and to ice was present over this part of the hand. The patient was then compelled to return to his home in Jamaica, and we were unable to examine him further.

Case 84.—*Bullet wound of the forearm, causing hyperalgesia over the distribution of the ulnar and internal cutaneous nerves.*

In September, 1901, at Blood River Poort, J. D., aged 21, a corporal in Gough's Mounted Infantry, was shot through the left forearm. His arm dropped at once, and the ulnar half of the hand became numb.

The bullet entered 4 cm. below the head of the radius on the outer surface of the forearm, and passed out on the anterior surface, 8 cm. below the internal condyle of the humerus.

We first saw him at Netley on March 2, 1902. He complained of a constant tingling pain, particularly troublesome in cold weather, over the whole ulnar side of the forearm and hand. He had also noticed that the affected portion of his palm sweated more than a similar part of the sound hand.

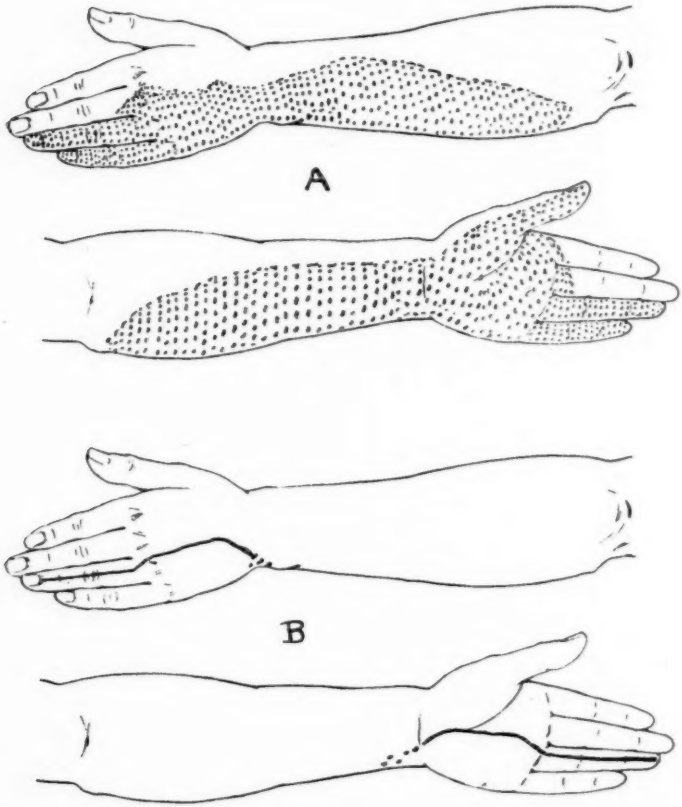


FIG. 37.

To illustrate Case 84.
A shows the extent of the hyperalgesia.
B the extent of the loss of sensation to light touch, and to the intermediate degrees of heat and cold.

Running downwards from the scar on the anterior surface of the forearm was an area of hyperalgesia extending on to the hand (fig. 37). It could be marked out with ease by dragging a point from the sound towards the affected side of the forearm and hand, or by picking up the skin.

On the anterior surface of the forearm, the boundary of the hyperalgesic area ran downwards towards the wrist, a little to the radial side of a line continued upwards from the axis of the ring finger. At the junction of the middle and lower thirds of the forearm, the area extended towards the radial side, reaching the proximal portion of the thenar eminence; from this point it was bounded by a line continued to the radial edge of the thumb-nail. The whole of the palmar surface of the hand and fingers was hyperalgesic with the exception of the index and the terminal two phalanges of the middle finger (fig. 37, A).

On the dorsal (extensor) surface, the boundary of this area of hyperalgesia corresponded in its upper two-thirds to a line continued upwards to the scar from the cleft between the middle and ring fingers. In the lower third of the forearm it swung outwards, reaching nearly to the tendon of the extensor ossis metacarpi pollicis at the wrist. Thence it was continued down towards the knuckle of the middle finger. The whole of the dorsal surface of the hand up to this line, the dorsal surface of little and ring fingers, together with the ulnar two-thirds of the first phalanx of the middle finger, were tender.

Cotton-wool and the minor degrees of temperature could not be appreciated over the full area in the hand supplied by the ulnar nerve (fig. 37, B). Sensation to prick and to the extremes of heat and cold was everywhere present.

There was no marked muscular wasting, and all the muscles acted perfectly and reacted to the interrupted current.

Case 28.—*Division of the median and ulnar nerves, together with several tendons. Primary union of tendons. Secondary suture of the nerves after the tendons had healed. Condition of deep sensibility.*

G. B., a carpenter, aged 24, cut his right forearm with glass on September 24, 1902. The wound was explored the same day without an anæsthetic; several divided tendons were sutured, but the nerve injury was not discovered. Two or three days later he noticed that he had "lost all feeling" in the palm of the hand and fingers.

He was admitted to the London Hospital on April 15, 1903, and we saw him the following day. He had been at work for five weeks; a week after he had begun work a blister had appeared on the fingers, which had burst and discharged, leaving an ulcer.

In order to treat this condition he placed the fingers in hot water, and so produced further blisters. This resulted in the following condition, which was present when we first saw him. A superficial ulcer occupied the surface of the last two phalanges of the index finger; the nail had disappeared, leaving a granulating surface discharging pus. The terminal phalanx of the

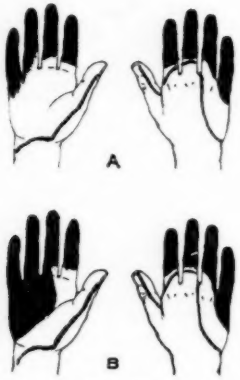


FIG. 38.

To illustrate Case 28.
A shows the loss of sensation before the operation.
B shows the loss of sensation produced by the operation of April 17.

middle finger was in a similar condition. No blisters had appeared on the other fingers, although the whole hand had been placed in the hot water.

A flap-shaped scar was present on the anterior surface of the forearm, extending downwards and radialwards from 8 cm. above the head of the ulnar to 3 cm. above the fold of the wrist at the tendon of the flexor carpi radialis; here it changed its direction and ran almost vertically upwards for 3 cm.

The hand was in the position typical of ulnar paralysis, and all its intrinsic muscles were wasted and paralysed; they did not respond to stimulation with the interrupted current.

Sensibility to light touch and to prick were lost over the areas in fig. 38, A.

On April 17 the condition of the nerves was explored. The median was found to have been completely divided and its ends separated, the lower being united to a tendon. The upper end of the ulnar was bulbous and united to the lower by a thin strand of tissue. Both nerves were reunited after the ends had been freed and freshened.

This operation resulted in a considerable increase in the area insensitive to prick and to the more extreme degrees of heat and cold (fig. 38, B).

No improvement in the sensory condition of the hand took place until after August 23. The area insensitive to light touch and to prick remained as extensive and well defined as immediately after suture. He failed to appreciate ice, and water at 50° C. over the area insensitive to prick, and over the area anæsthetic to cotton-wool he could not recognise water at 22° C. and at 40° C. Sensibility to deep touch was present and well localised everywhere except over the little finger. To the compass test applied over the median half of the palm, he failed entirely at 3 cm., but when the two points were applied successively, he made no mistakes at 2 cm. and was rarely wrong at 1·5 cm.

By September 27, he could appreciate a prick and the more extreme degrees of temperature over the whole of the palm and dorsum of the hand, the fingers still remaining insensitive to these stimuli. By December 20, all analgesia had disappeared and he could appreciate stimulation with cotton-wool over the dorsum of the hand, but if this area was shaved, it was found to be entirely insensitive to this stimulus.

Case 43.—*Complete division of the musculo-spiral nerve.*

F. L., a boy of 9, fractured the lower end of his right humerus on June 28, 1903. Two days later an open operation was performed in order to reduce the deformity.

Paralysis of the muscles of the forearm supplied by the musculo-spiral nerve resulted from this operation. In consequence of this condition, he came under the care of one of us at the Poplar Hospital for Accidents on July 28, 1903.

All the muscles in the forearm supplied by the musculo-spiral nerve were wasted and paralysed; they did not react to the interrupted current, but responded with a characteristically

sluggish contraction to the constant current to which they reacted more readily with the positive than with the negative pole.

No loss of sensibility to any form of stimulation could be discovered, either in the forearm or hand.

On August 3, an exploratory operation showed the nerve to have been completely divided. The two ends were adherent to the bone and united by a thin strand of fibrous tissue. They were freed, freshened, and again united.

No change in sensation was produced by this operation, and the wound healed by first intention.

On February 22, 1904, the extensors of the wrist acted voluntarily, and responded to stimulation with a strong interrupted current. All the affected muscles acted voluntarily on May 2, but no response could be obtained to stimulation with the weak interrupted currents he would tolerate at this date, although they reacted briskly to the normal pole of the constant current. On June 29, they reacted to the interrupted current, and by September 14, 1904, all muscular wasting had disappeared.

Case 44.—*Surgical division of the radial nerve* (*r. superficialis n. radialis*) *at the wrist, followed by division of the posterior branch of the external cutaneous at the elbow. Subsequent division of the branch of the median to the ulnar half of the thumb.*

L. L., a dressmaker, aged 33, came under our care in August, 1904.

For five years she had suffered from a "neuralgic" pain, starting in the left thumb and shooting up the arm to the axilla. If she accidentally knocked the thumb, the pain became so severe that she "almost fainted."

The ulnar portion of the terminal phalanx of the thumb was tender to pressure with the head or point of a pin, but all forms of sensation were otherwise normally present. The radial and musculo-spiral nerves were tender throughout their course.

On August 27, 1904, the radial nerve was exposed just after it had passed under the tendon of the supinator longus and an inch removed.

As the result of this operation, light touch, and water at 23° C. and 40° C. were not appreciated over the area in fig. 39, A. The boundary of this loss of sensation on the thenar eminence and both borders on the dorsum of the thumb were well defined, while that on the dorsum of the hand merged gradually into parts of normal sensibility. A prick, ice, and water at 50° C. were appre-

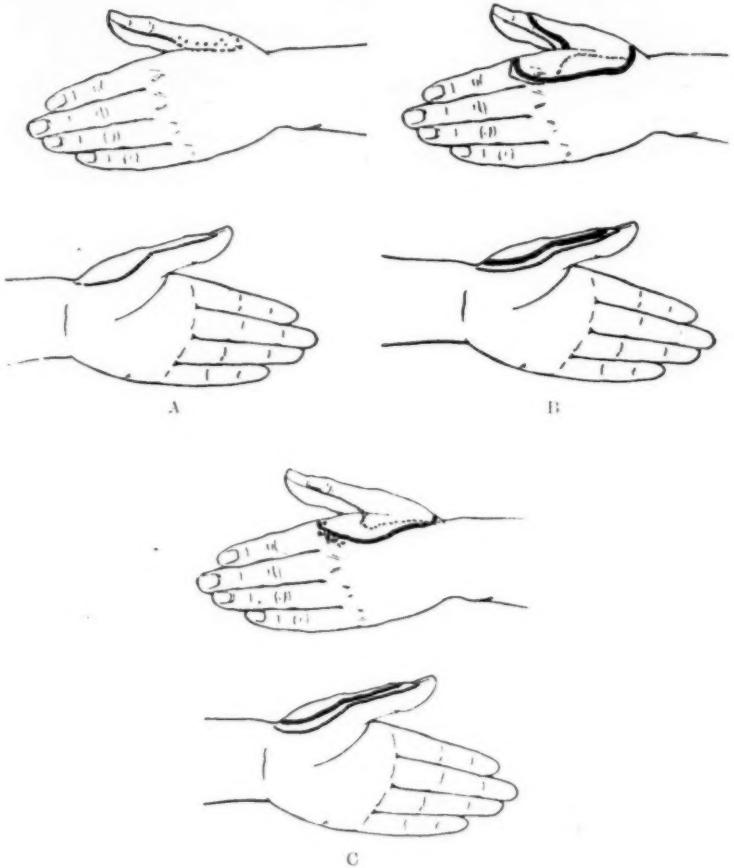


FIG. 39.

To illustrate Case 44.

A shows the area which became insensitive to light touch in consequence of division of the radial nerve (r. superficialis n. radialis) at the wrist.

B shows the areas of loss of sensation produced by subsequent division of the posterior branch of the external cutaneous nerve at the elbow. The thick line encloses the parts insensitive to prick, the thin line the parts insensitive to cotton-wool.

C shows the additional loss of sensation on the thumb caused by subsequent division of the branch of the median nerve to the ulnar half of the thumb.

ciated everywhere. The tender area on the dorsum of the thumb was still present, although the tenderness was less marked. Consequently, on September 9, 1904, the posterior division of the external cutaneous nerve was divided at the bend of the elbow. This operation increased slightly the area insensitive to light touch on the dorsum of the hand, but left it unaltered on the thenar eminence and thumb. A prick and the more extreme degrees of temperature could not be appreciated over an area almost as extensive as that within which light touch was lost, but a small area of dissociated sensation was present on the dorsum of the hand sensitive to cotton-wool, but insensitive to prick and to all degrees of temperature (*vide* fig. 39, B). Deep touch was appreciated over the whole of the affected area. No loss of sensation resulted in the forearm from this operation.

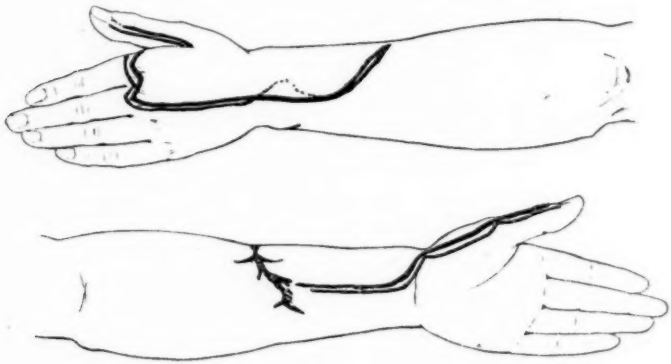


FIG. 40.

From Case 47, to show the area of loss of sensation produced by the accidental division of the radial (r. superficialis n. radialis) and external cutaneous nerves. The jagged scar is represented running across the flexor surface of the forearm. The area insensitive to light touch is enclosed by a thin line, that insensitive to all cutaneous stimulation by a heavy black line.

As a little tenderness still remained at the extreme ulnar border of the tip of the thumb, the branch of the median nerve supplying the inner side of the thumb was divided on October 5, 1904. This rendered the ulnar border of its terminal phalanx entirely insensitive to all forms of cutaneous stimulation (fig. 39, C).

Case 47.—*Accidental division of the radial* (*r. superficialis nervi radialis*) *and external cutaneous nerves in the forearm. The case illustrates the characteristics of deep sensibility.*

G. S., a cabinet-maker, aged 23, cut his left forearm with a broken window on July 23, 1903. The wound was sutured immediately, but suppurated severely, and he was admitted to the London Hospital with secondary hæmorrhage ten days later.

He first came under our observation on October 25, 1903.

On the radial border of the lower third of the forearm was a multiradiate scar, its centre situated 9 cm. above the wrist, depressed and adherent to the underlying structures.

All the movements of the hand and fingers were perfect, and there were no obvious changes in the appearance of the skin.

He was unable to appreciate a prick, light touch, and all degrees of temperature over an area on the forearm and hand shown in fig. 40. The boundary of the loss of each of these forms of sensibility was identical, except over a triangular area situated just above the wrist. Over this portion of the dorsum of the hand, measuring 5 cm. in length and 4 cm. in breadth at its widest part, cotton-wool was definitely appreciated, but sensibility to all degrees of temperature was abolished.

Deep sensibility was present over the whole of the affected area, and he localised well the point of application of the stimulus. He readily appreciated stimulation with cotton-wool rolled up into a pledget and applied vertically, or dabbed on to the hand. But he entirely failed to distinguish between the point of a pin and pressure with a steel rod 2 cm. in diameter. If the skin was raised from the underlying structures, he lost all power of appreciating pressure.

Over the affected area on the dorsum of the hand, he was unable to discriminate two points at 5 cm., applied simultaneously in a longitudinal direction. But when the points were applied successively, he frequently recognised the double nature of the stimulus, although the points were only 2 cm. apart. Over a similar portion of the sound hand he made no mistakes at 3 cm., and only two at 2 cm.

We had the opportunity of examining this patient on many subsequent occasions. The area of loss of all forms of cutaneous sensibility remained unaltered, and the triangular area of dissociated sensibility persisted; but the amount of sensation evoked by cotton-wool varied considerably, being less marked in the winter.

When we last saw him on September 11, 1905, this area was as well marked as when we first tested him, and the character of its sensibility remained unchanged. After shaving, it became entirely insensitive to cotton-wool, and the area of loss to this form of stimulation then corresponded exactly to that of the loss of prick.

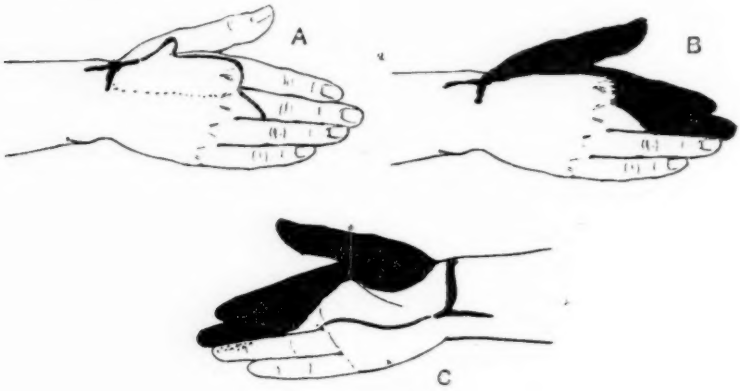


FIG. 41.

To illustrate Case 85.
A represents the area insensitive to light touch; the dotted line enclosed an area of diminished sensibility.
B shows the parts insensitive to prick and to heat and cold.
C shows the parts insensitive to prick in black and those insensitive to light touch enclosed by a line.

Case 85.—*Division of the median, radial and part of the external cutaneous nerves. Trophic changes in the skin of the insensitive fingers. Dissociated sensibility on the radial side of the back of the hand.*

T. S., a plumber, aged 30, was admitted to the London Hospital on May 12, 1902.

Six weeks previously (March 29) he had put his right hand through a glass panel, cutting the wrist. The wound was sewn up the next day, and "never properly healed." He noticed that the radial half of the hand was numb immediately after the accident.

A transverse scar ran round the radial portion of the wrist from the base of the third metacarpal bone on the back of the

hand to the second on its palmar surface. In the centre of this wound was a small granulating area.

The hand was held adducted to the ulnar side and slightly flexed. The outer group of thenar muscles was wasted, and the abductor and opponens pollicis were not acting and did not respond to stimulation with the interrupted current. The flexor and extensor tendons of the thumb, the flexors of the index finger, and the radial extensors of the wrist, were seen to be divided on throwing the muscles into action.

The skin over the whole palm was desquamating; the middle and index fingers were covered with rough scales, but the little and ring fingers had already completely desquamated.

The boundaries of the area of loss of sensation corresponded almost exactly on the palm for all forms of cutaneous stimulation, and the borders were well defined (*vide* fig. 41). On the dorsum, over the distal portion of the first interosseous space, light touch, though diminished, was appreciated over a small triangular area where he was entirely insensitive to prick and all degrees of temperature.

The boundary of the loss to light touch was here ill-defined, and the area of loss merged on the ulnar side into parts of normal sensibility.

On June 3, the median and radial nerves were exposed. They were found to have been divided, and were reunited.

No change in the sensory condition of the hand resulted from this operation. It was not until November 16, 1902 (166 days after suture), that the analgesia had retreated from the palm. By September 6, 1903, he could appreciate a prick and the more extreme degrees of temperature everywhere over the affected hand except the terminal phalanges of the index and middle fingers. The area insensitive to cotton-wool remained as extensive and well defined as before suture.

Up to this date, burns and injuries arising during his work as a plumber had resulted in the formation of ulcers, but with the return of sensibility to prick all the ulcers had healed and none appeared subsequently.

By December 20, 1903 (565 days), the area on the palm and dorsum of the hand anæsthetic to light touch had diminished in extent, and on January 31, 1904, occupied only the last two phalanges of the fingers and terminal phalanx of the thumb; water at 24° C. and at 40° C. were appreciated except over these parts. To the compass test at 2 cm. he made only two mistakes, but 1·5 cm. was obviously below the threshold.

On February 24, 1904 (634 days), the opponens and abductor reacted to the interrupted current, but no voluntary movement was observed until August 28. At this time he was still insensitive to cotton-wool and the intermediate degrees of temperature over the terminal phalanges of the index and middle fingers.

Case 86.—*Bullet wound of the ulnar and musculo-spiral nerves. Hyperalgesia over the peripheral distribution of both nerves. Loss of sensation to light touch and to the intermediate degrees of heat and cold over the full ulnar area.*

R. M., a corporal in the Imperial Yeomanry, serving in South Africa, was shot through the left shoulder at fifty yards, on November 25, 1901.

He immediately felt as if he had received "a sharp blow on the shoulder" and found that his arm was numb and useless. He fainted and, falling from his horse, lay on the veldt for about two hours. When he regained consciousness, he had so far lost all sense of the position of the limb that, as he told us, he "felt for it here and it was there."

Seven days after the injury, the shoulder began to swell and "was swollen to several times its usual size for four or five days." Ten days after he had been wounded, pain began in the shoulder, and "gradually worked down the arm, leaving the shoulder free, settling in the hand." The wound was completely healed in three weeks.

He came under our observation at the Royal Victoria Hospital, Netley, on March 24, 1902, and again in August of the same year. No change took place in his condition during this time.

The wound of entry was situated at the junction of the arm, with the anterior axillary fold 7·5 cm. below the coracoid process. The wound of exit lay over the inferior border of the scapula, 11·5 cm. below its spine. All the muscles of the shoulder and arm were wasted, and the biceps being less affected than the others stood out prominently. All except the triceps were acting voluntarily. The muscles of the forearm were wasted and the wrist was dropped; all power of extension of the wrist and fingers was lost and the supinator longus was not acting. All the flexor muscles acted feebly. The whole hand appeared wasted, and the muscles supplied by the ulnar nerve were paralysed.

The biceps, extensors of the wrist and fingers, supinator longus, interossei and adductors of the thumb did not react to the interrupted current.

The skin of the affected palm was smooth, pink and mottled. The little finger and ulnar border of the hand were blue and wrinkled. All the fingers tapered and the nails were kept long on account of the pain caused by cutting them. They were smooth, and showed excessive curving, both transversely and longitudinally.

He complained of pain in the hand "as if it were going to burst," and said: "I have often looked at it, fancying it must be

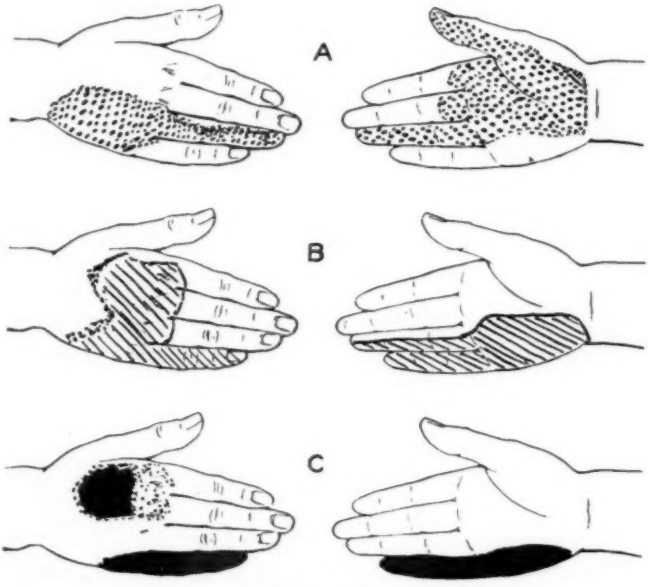


FIG. 42.

To illustrate Case 86.
A shows the extent of the hyperalgesia.
B shows the area insensitive to light touch.
C shows the area insensitive to prick and to all degrees of heat and cold.

bleeding." The pain was continuous, and he could only obtain relief by rubbing it with olive oil, which eased him for about an hour.

Extreme hyperalgesia existed over the area shown in fig. 42, A. Sensibility to cotton-wool was absent over the full ulnar area, which merged on the dorsum, by means of a band of diminished

sensibility into an area on the radial side within which he usually failed to recognise a touch with cotton-wool. Water at 22° C. and at 38° C. were not appreciated over that portion of the hand where light touch was affected. He was unable to appreciate prick, ice, and water at 55° C. over the area shown in figure 42, B.

After leaving Netley on August 26, 1902, he attended a civil hospital until February, 1904, and was treated with massage and galvanism. All pain and tenderness gradually disappeared.

When we saw him again on April 3, 1905, all the muscles of the upper limb were wasted. Those on the extensor surface of the limb acted voluntarily except the extensor longus pollicis, and all responded to stimulation with the interrupted current.

None of the intrinsic muscles of the hand acted, or reacted to the interrupted current.

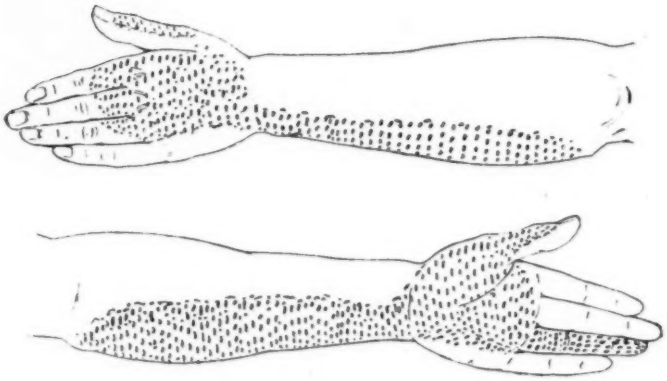
All trace of hyperalgesia had disappeared, and he was able to appreciate a prick and the extreme degrees of temperature over the whole of the affected hand. He was anæsthetic to cotton-wool over the ulnar area on the palm, but appreciated it everywhere on the dorsum, even after the hand was shaved.

Case 64.—*Bullet wound of the arm injuring the musculo-spiral, median and internal cutaneous nerves. True hyperalgesia. Two forms of cutaneous trophic change.*

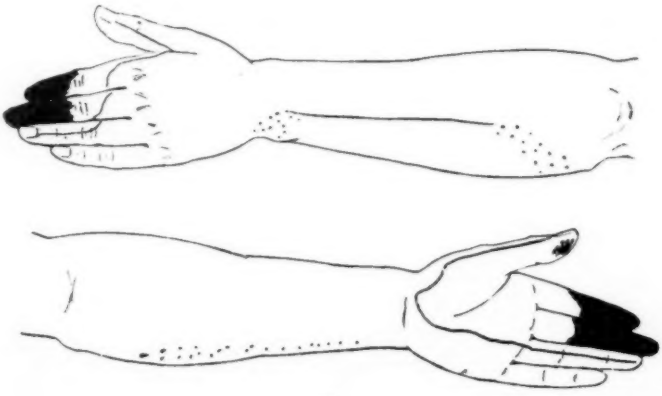
James W., aged 23, a corporal in the Imperial Yeomanry (Royal Victoria Hospital, Netley). On August 1, 1901, he was shot through the left arm with a Martini bullet. He fainted and fell from his horse, but suffered no pain. The Boers came up, took what they wanted from him, and left him lying for two days and one night on the veldt. He was then taken to hospital, but the "wound became very foul," and did not heal for more than five weeks.

At first the arm was entirely painless; but about a month after the injury the hand began to be painful. The pain steadily increased until it became constant. It did not vary to any considerable extent except in cold weather. In the winter, it was scarcely troublesome so long as the hand was exposed to cold, and cold water always removed the pain for a time.

We first saw him on March 3, 1902. He was then a well-built, healthy looking man, with a somewhat anxious expression. He carried his arm in a sling with the hand exposed, and was evidently terrified lest it should be touched or jarred.



A



B

FIG. 43.

To illustrate Case 64.

A shows the area that was hyperalgesic.

B shows the area insensitive to light touch enclosed in a single line. The parts insensitive to prick and to all degrees of heat and cold are coloured black.

The wound of entry was situated 1½ ins. (4 cm.) above the external condyle of the humerus. It was triradiate in shape, measuring 1¼ in. (3 cm.) by ½ in. (1·2 cm.). Two and three-quarter inches (7 cm.) above the internal condyle was the wound of exit, oval in shape, 1 in. (2·5 cm.) by ¾ in. (2 cm.) in size. Both wounds showed a tendency to keloid formation.

The whole of the left hand was smooth and of a bluish-pink colour, the two terminal phalanges of the index and middle fingers were cold and blue. The radial half of the palm and the index and middle fingers did not sweat, whereas the whole of the remainder of the palm was sweating profusely.

The muscles on the extensor surface of the forearm and the outer group of the thenar muscles were much wasted. No extension was possible at the wrist, but, with the fingers extended, the hand could be raised to the horizontal. The supinator longus was acting well. All movement was absent in the abductor and opponens pollicis. All the muscles supplied by the ulnar nerve reacted perfectly to the interrupted current, but no reaction was obtained from the opponens and abductor pollicis. Neither of the extensors of the wrist nor those of the fingers reacted to the interrupted current, but all the remaining muscles of the forearm responded. The extensors of the fingers acted feebly, but failed to respond to faradic stimulation. The muscles supplied by the median nerve neither acted voluntarily nor reacted to the interrupted current.

He complained of great tenderness over the ulnar half of the palm of the hand, and over the greater part of the dorsum. The head of a pin caused considerable pain when the limits of the area in fig. 43, A, were reached. Sensibility to cotton-wool was lost over an area that occupied the ulnar half of the forearm on the dorsal surface. To the radial side, this anæsthetic strip was sharply marked off from the remainder of the arm, but the proximal and distal ends, and the limits of loss to light touch on the front of the forearm, were indefinite, merging gradually into parts of normal sensibility. On the palm of the hand and over the fingers, light touch was lost within the area shown in fig. 43, B, corresponding to that commonly seen after division of the median nerve. Sensation to prick was absent from the index and middle fingers over two and a half phalanges on the palmar aspect, and the two terminal phalanges on the dorsal surface. Water at 40° C. was not appreciated over the area where light touch was lost on the forearm and palm of the hand. Ice, and water at 50° C. produced a sensation of cold and of heat, excepting over those

parts of the fingers insensitive to prick. Tested with the compass points over the normal palm and over the ulnar portion of the affected palm, the record was perfect at 1·5 cm. Over the radial half of the palm of the affected hand within the limits insensitive to light touch, but sensitive to prick, ten stimuli with the two points at 3 cm. were called "one"; right answers were given in every case when one point only was used. By this test there was no material diminution of sensation over the ulnar half of the affected palm, but over the median half the points at 3 cm. were evidently below the threshold of sensation.

On March 27, 1902, we saw him again and found that a sore had made its appearance over the terminal phalanx of the middle finger; it first appeared as a blister without known cause, and was entirely painless. It had all the appearances of a trophic sore of a kind not infrequently seen over totally analgesic parts. We were told by the medical officer in charge of the case that in December, 1901, a herpetiform rash had made its appearance over the ulnar half of the palm of the hand, and part of the little and ring fingers, that is to say, within the area of true hyperalgesia. Thus, this man showed both forms of trophic-lesion of the skin which make their appearance in consequence of injuries to nerves.

On our first visit we had noticed that the nails of the thumb, index and middle fingers were abnormally curved, both in a transverse and longitudinal direction. He stated that these nails did not grow so quickly as those of the normal hand, and this statement was borne out by measurements made at our second visit. In the twenty-four days which had elapsed, the growth of the nails of the two sides was as follows:—

	Sound Hand.	*Affected Hand.*
Thumb	5 mm.	3 mm.
Index	6 mm.	1·5 mm.
Middle	6·5 mm.	4 mm.
Ring	5 mm.	5 mm.
Little	4 mm.	4 mm.

Thus, although the nails of the ring and little fingers showed an equal amount of growth on the affected hand, those of the index and middle fell far behind.

We were able to confirm our previous observations on the limits of the hyperalgesia, and loss to light touch. The extent of the loss to prick was somewhat less than on our first visit.

Case 57.—Bullet wound of the great and small sciatic nerves.

J. W. B., a private in the 1st Manchester Regiment, was wounded at Witklip on October 4, 1901. He was ambushed when on water picket and shot from a distance of about twenty yards. He at once felt great pain down the back of the leg.

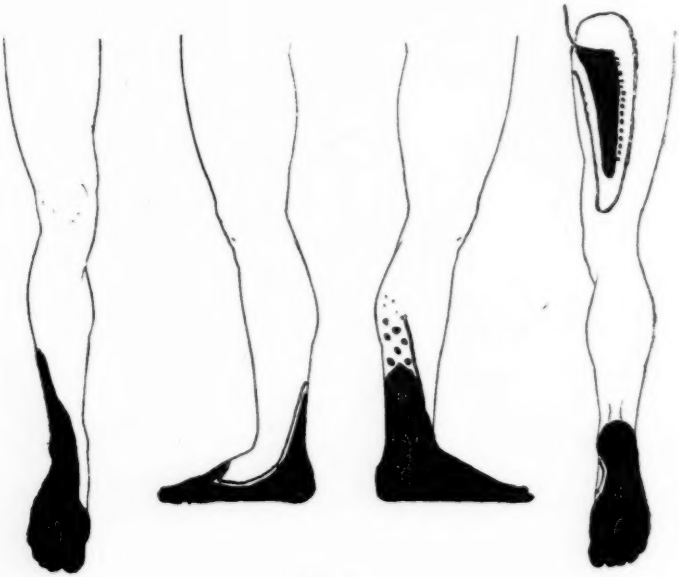


FIG. 44.

To illustrate the loss of sensation produced in Case 57 by an injury to the great and small sciatic nerves. Total loss of cutaneous sensibility is represented in black. Loss of sensation to light touch is enclosed by a line.

The wound was dressed half an hour later, and he was taken to Leidenberg Hospital the same day.

He came under our observation at Netley in August, 1902. The wound of entrance, situated 2·5 cm. to the right of the spine of the third sacral vertebra, had not yet healed; 4 cm. anterior to the upper border of the great trochanter was a small surgical scar through which the bullet had been extracted.

All the muscles of the lower limb supplied by the sciatic nerve were wasted, and, with the exception of the hamstring muscles,

were paralysed. None of the muscles supplied by the sciatic nerve contracted to the interrupted current, and to the constant current all reacted sluggishly. These muscles responded more easily to the positive than to the negative pole, but no reaction could be obtained from the hamstring muscles, even with a current sufficiently strong to cause contraction in the muscles on the anterior surface of the limb.

Extending downwards from the fold of the buttock for about 40 cm. was a strip, within which he was unable to appreciate prick and the more extreme degrees of temperature. Surrounding this in every direction, and extending on to the buttock, was an area anæsthetic to cotton-wool (fig. 44).

Over the greater part of the foot and outer portion of the lower third of the leg, light touch, prick, and all degrees of temperature were unappreciated; the borders of loss of sensation to each of these stimuli were almost exactly co-terminous.

This area was continued upwards into parts insensitive to cotton-wool, and to intermediate temperatures, but sensitive to prick, and to the more extreme degrees of heat and cold. Above the loss of sensation merged gradually into parts of normal sensibility.

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THE STRUCTURE AND FUNCTION OF THE TASTE-BUDS OF THE LARYNX.

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With 2 Plates: Plates II. and III.

On the minute anatomy of the taste-buds of the tongue much work has been done, but relatively little on the buds of the larynx. Yet in this cavity, on account of the isolated position of the buds, their structure can be more easily discerned and the nerve supply more closely studied than in the mouth. The investigations which are described in this paper have been chiefly directed toward the morphological characteristics of the laryngeal buds, especially the nerve supply, including the nerve-endings. It was hoped that such investigations would throw some light upon the physiological action of taste-buds in general and upon any additional physiological action which the taste-buds of the larynx might possess.

The tissue examined was obtained from man, from the monkey, dog, and rabbit. The method employed was chiefly the *intra vitam* injection of methylene blue, as described in a former paper (Wilson, 1904). The tissue was usually counterstained with orange G acid fuchsin. At the same time sections were stained by the Golgi method, by iron hæmotoxylin, and by gentian violet.

In the larynx the taste-buds, first described by Verson, in 1871, are found on the laryngeal surface of the epiglottis and the medial and lateral surfaces of the arytenoids. They are usually met with in groups, but never closely packed together as in the tongue. Buds are found only in the squamous epithelium. They do not project beyond the surface, but lie in a very shallow saucer-like depression (Shofield, 1876).

They extend through the whole depth of the epithelium, and each rests on a broad papilla of relatively dense connective tissue, through which vessels and nerves enter the buds. These papillæ are not always prominent, and may be absent; when present, they are easily observed, since over the cartilage of the epiglottis the epithelium possesses relatively few papillæ.

Notwithstanding the shallow saucer-like depression of the epithelium in which the buds lie, their pores are very much exposed, and so are in marked contrast to the concealed nature of the taste-pores of the tongue (Plate II. A). Each bud is surrounded, except at its base, by a wall made up of epithelial cells, which are flattened laterally and imbricated (fig. 1; compare extrabulbar cells of Gräberg, 1899). A

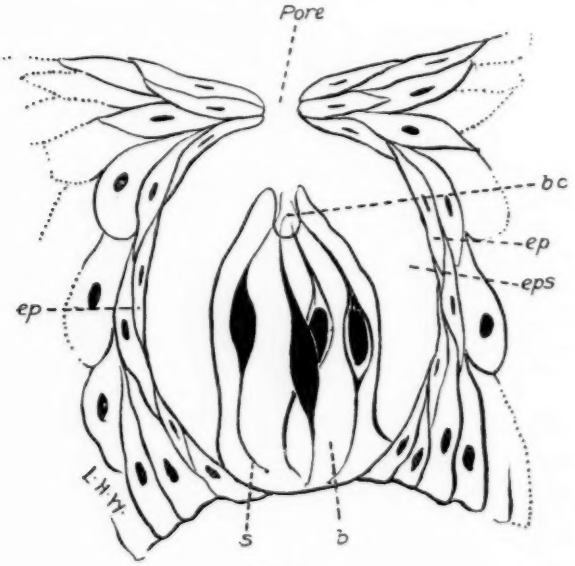


FIG. 1.

Section of the epiglottis of a dog, showing the arrangement around the bud of the epithelial cells—flattened and imbricated (*ep*). Taste-bud (*b*) retracted from the sides, but attached at base leaving a space (*eps*). Within the bud four spindle-shaped cells (*s*) project into bud cavity (*bc*).
Zeiss $\frac{1}{12}$ *oil immersion. Comp. occ.* 4.

condition of cornification can be observed in many of them. They fit closely to each other, and are adapted to the shape of the bud. Towards the surface the cells are so adjusted as to form a clean-cut edge around the pore, sloping slightly in a radial direction to it. The pore proper is formed entirely by these epithelial cells. Towards the subepithelial tissue the cells have their bases flattened and so extended as to embrace the papilla. There is here, therefore, such a modification of the epithelium adjacent to the bud that it may be regarded as forming a protective capsule, the closely packed epithelial cells being in marked contrast to the loosely arranged cells of the bud. To this capsule the bud is attached by protoplasmic bands, and out of this epithelial setting, after fixation, it easily drops.

The laryngeal taste-bud, like that of the tongue, has two types of cells, the spindle-shaped cell and the supporting cell, also a flasked-shaped cavity in its upper segment.

(1) The spindle-shaped cell (fig. 1 and Plate II. B) extends the whole length of the bud; it is not confined to the axial region. Its central termination, long, fine, and unbranched, reaches to the connective tissue of the papilla, but not into it. Peripherally its cytoplasm is prolonged into a very fine hairlike process which projects into the cavity of the taste-bud, and may even reach to the taste-pore. In vital staining with methylene blue, not only does the nucleus stain readily, but the facility with which the whole cell takes up the dye is in marked contrast to the non-reaction of the supporting cell and of the surrounding epithelial cells to the dye. In these cases the cell is very sharply outlined.

The evidence in support of the special sense function of the fusiform cell is based on :—

(*a*) The fact that it colours readily with neurotropic dyes, as opposed to the non-colourability of the supporting cell.

(*b*) The morphological character of the cell.

(*a*) Primary colourability as a test for a neuro-epithelial cell, though of great value, is subject to so many exceptions that alone it is open to objections. Methylene blue, although neurotropic, is not monotropic (Ehrlich, 1902). It is impossible to deduce from primary colourability that we are

dealing with a nerve termination. Some cells which so stain cannot be recognised as neural cells; for instance, one cell in the epithelium which readily takes up the dye is the so-called "wandering cell," a cell which has been mistaken for and described as a ganglion cell (Dogiel, 1903). In the bud, however, we have two varieties of cells, one of which, the spindle-shaped cell, shows the neurotropic character, the other does not; so we are justified in assuming that the former possesses a certain chemical constitution which allies it more closely to the nerve-cell.

(*b*) When to this we can add such morphological characteristics as its peripheral process with its relation to the pore, its analogy to other special sense-cells, we have support for the belief that the fusiform cell is specially engaged in the mediation of the sense of taste.

(2) The second type of cell, the so-called supporting cell, differs in no respect from the corresponding cells in the buds of the tongue. Its shape varies very greatly, but there are not two types of this cell, one peripheral and one central. The irregularity is due in some degree to fixation. The cells are loosely applied and adjusted to each other, to the taste-cells, and to the epithelium around, leaving spaces through which leucocytes may wander (Ranvier, 1888). Under fixation they readily shrink and may withdraw from each other, but chiefly as a bud from the epithelial wall from which they may separate at any point. When this shrinkage occurs, the intercellular bridges which pass from the epithelial wall to the supporting cells are easily observed and without doubt distort the cell wall. While this is so, the general relation of the supporting cell to the taste-cell and its general outline in cross-section prove that we have to do with a cell which readily adjusts its contour to the surrounding parts. In the centre of the bud it appears somewhat triangular, with the fusiform sensory cell applied to the flattened and slightly concave surface; at the periphery there is a similar adjustment of the external surface to the epithelial wall—convexity to concavity. Its general appearance and its mobility of surface suggest a cell protoplasm easily susceptible to external influences.

The cavity, first described (v. Ebner, 1897) in the taste-buds of the tongue, is generally flask-shaped (fig. 1 and Plate II. A), and has its mouth directly opposed to the taste pore. It extends but a short distance into the upper segment of the bud, and is formed by the approximation of the peripheral ends of the supporting cells. Projecting into it are the peripheral ends of the taste-cells which pass between the supporting cells. The contents of this cavity are unstainable; it probably contains, as in the tongue (Poirier et Charpy, 1902), a clear liquid, in which the terminal points of the gustatory cells are bathed.

Shrinkage of the bud from its epithelial capsule through the action of a fixing agent is more common than in the taste-buds of the tongue of the same animal. It is so constant a feature that one may well enquire whether the protoplasm of the bud is not more capable of reacting to fixatives than is the protoplasm of the surrounding cells.

From the stability of the capsule, from the minuteness of the pore, from the relative density of the subepithelial tissue at the insertion of the bud, from the ease with which shrinkage occurs, the impression is given that the bud is an organ subject to very little external pressure, and that the cells of which it is composed are capable of reacting freely to any agent which may influence them at their exposed parts in the central flask-shaped cavity of the bud.

The anatomical investigations of the relation of nerve-endings to taste-buds have been made on those of the tongue, with the exception of some work done by Arnstein (1897) on those of the larynx. There is still much doubt as to how the nerves end. It is generally admitted that there is a subgemmal plexus (Retzius, 1892), but as to the nerves that form it and how its constituent elements are distributed, we have as yet no precise information. Thus Jacques (1894) derives perigemmal, intragemmal and intergemmal fibres from a subgemmal plexus, which can thus bear no similarity to the subgemmal plexus or "cupula" of v. Lenhossék (1893) and Arnstein (1897), still less to the plexus of special sensory fibres described by Dogiel (1897). Moreover, no sufficient evidence has been advanced for the

view that certain nerves going to the bud are sensory, while others are nerves of special sensation. Again, though Arnstein (1893) appeared to have clearly shown that Fusari (1891) was mistaken in describing the actual connection of the nerve-fibre with the fusiform cell, this connection appears to be still maintained by some authors (Finocchiaro, 1904). Lastly, there is the question of the presence of a ganglion cell in the subgemmal plexus, which Jacques (1894) supports, and Roeske (1897) denies.

I find that the mode of ending of the nerves in the taste-buds of the larynx is as complex as that of the tongue. Lying under the epithelium of the laryngeal surface of the epiglottis and aryteno-epiglottic fold there is a subepithelial plexus composed of both medullated and non-medullated fibres. From this plexus there go to the taste-buds not less than two, and usually three or more, nerve-fibres, some fine varicose fibres, others, which are at first medullated, but lose their sheath at a varying distance between the plexus and the bud. These fibres divide repeatedly, so that at the base of the bud the nerves are very numerous and individual fibres are often difficult to follow (Plate II. A). But two distinct groups can, as a rule, be distinguished: (1) Those that break up to form a plexus at the base of the bud, with prolongations within the bud; and (2) those which go more or less directly round the bud. The latter may branch in the plexus, but there is no anastomosing nor interlacing of branches, as occurs with the fibres of the plexus. In this complex arrangement three groups can therefore be distinguished:—

(I.) Subgemmal plexus; (II.) Intragemmal nerve-fibres; (III.) Perigemmal nerve-fibres.

The so-called intergemmal fibres (Jacques, 1894) are nerves distributed to the epithelial cells which lie between the buds (Plate II. A). They have no direct connection with the bud, and differ in no way from the nerves to the adjacent epithelium.

(I.) The subgemmal plexus Plate III. B, and Plate II. A) lies in the subgemmal connective tissue, and may begin at some distance beneath the bud. The apex is central towards

the subepithelial plexus; the base is broad, and applied to the convex central end of the taste-bud. It is formed by branching and apparent anastomosis of one or more fibres which come from the subepithelial plexus. The winding and interlacing of these fibres are very complex, and often are made more difficult to follow because of the "End-bäumchen," which branch around and among them, but from which they are distinct. The plexus is continued within the bud, so that on cross-section the basal part of the cells of the bud appears to be embedded in the plexus.

(II.) There are two sources from which intragemmal fibres arise: (1) From the subgemmal plexus; (2) directly from the subepithelial plexus.

(1) The fibres connected with the subgemmal plexus are very irregular in their course. At the base of the bud they have a plexiform arrangement, and surround the bud cells. Two varieties of endings are seen in connection with this group (Plate II. B): (*a*) A branching and interlacing network around the cells. This is well marked in the lower third of the bud, less in the middle, and only slightly at the upper third. (*b*) Knob-like endings most marked at the upper third of the bud; they lie on the cells.

(2) A few non-medullated fibres come directly from the subepithelial plexus and take no part in the formation of the subgemmal plexus (Plate II. B, and Plate III.A, where a fibre is marked v.). They may run to the bud outside the subgemmal plexus, or they may pass through it. In the latter case they run a course more or less direct towards the bud; they may divide in the plexus, and their rami run in opposite directions, but in no case do they show such complex interlacing as do the fibres of the plexus. Their course to the bud is by no means difficult to follow. Within the bud they are not always easy to follow, but the general trend of all the branches is towards the apex of the bud.

(III.) The perigemmal nerve-fibres (Plate II. C and A) form a plexus of non-medullated varicose fibrils which lie around the bud, forming at the apex a circle around the pore (Lenhossék, 1893). They arise from medullated nerves which come from the subepithelial plexus, but which lose

this sheath before reaching the base of the bud. They may pass through and even branch in the subgemmal plexus. On cross-section branches may at times be seen to pass from the perigemmal plexus within the bud.

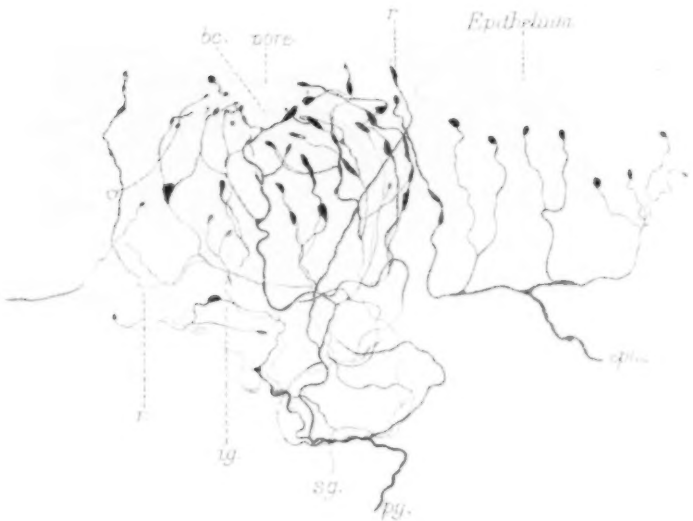
That some of these fibres are sensory as distinct from nerves of special sensation is demonstrated by the following; if we assume that one nerve-fibre carries a special sensation, or if we assume that the special sense organ of taste must have, like the eye or ear, special sensory fibres: (*a*) There can frequently be seen a nerve-fibre dividing into two trunks, one of which goes around or within the bud, the other to the surrounding epithelial cells (Plate II. A). (*b*) Occasionally, and more often near the base of the epiglottis and in the aryteno-epiglottic fold, a division at a node may send one fibre to the bud, another to an unencapsulated nerve-ending, as, for instance, a subepithelial end-tree (Plate III. A). The general course of these fibres is to surround the bud. Their terminals are directed to the apex of the bud to end near the bud cavity.

There are other fibres independent of these, different in structure and mode of distribution, which lie principally at the basal part of the bud and which form the subgemmal plexus and its continuation with the bud. These we regard as nerves of special sensation.

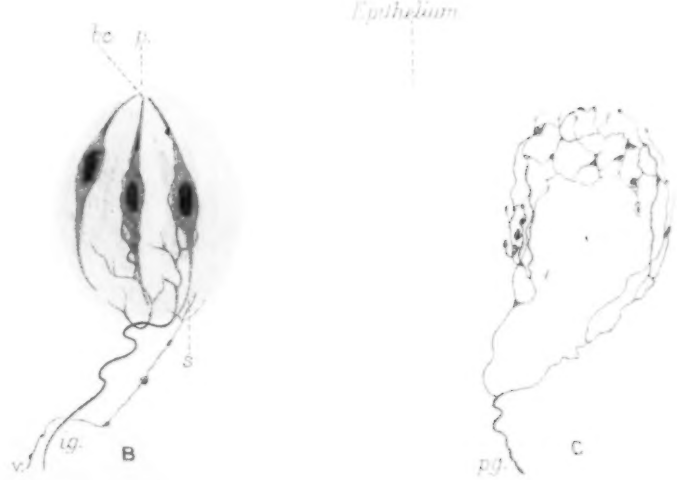
Ganglion cells have been described in connection with the nerves of the taste-bud by many investigators—Retzius, v. Lenhossék, Jacques, &c. Lenhossék (1893) gives a very guarded opinion: "Vollentwickelte Nervenzellen, wie etwa die des Sympathicus, sind es gewiss nicht" (p. 124). In the subgemmal plexus I have never seen sufficient evidence, in vital injection preparations, to enable the deduction to be drawn that swellings which may be seen on the nerves represent ganglion cells. Nor am I convinced of their presence by the evidence afforded by such swellings as are found in Golgi preparations.

The whole question of swellings in the course of the non-medullated nerve trunks is an interesting one, and many varieties are present in connection with the nerves of the taste-bud. For example, there are the well-known varico-

Plate II.



A



L.R.W. del.

Hale & Damelsson, Lith.

Plate III.

A

B

L.H.W. del.

Bale & Danielsson, Ltd. lith.

sities on the fine non-medullated nerve-fibres so constant in their presence and in their form both in non-fixed and fixed preparations that they cannot be passed over as merely *artefacts* or *post-mortem* changes (Kalius, 1905), but must be regarded as representing some peculiarity of the nerve-fibre. Thus it may represent a swelling on the axis cylinder or a point where the fibre is more exposed to external influences, just as at the node of a medullated nerve, where the sheaths are interrupted, there is a tendency to a darker and more profuse staining. Another variety of swelling appears at the point of division of an axis cylinder, due to a diffuse staining where its constituent parts are separating. This swelling will be obviously accentuated if, not two fibres branch off, as is usually the case, but three, four or five, as may at times be seen in the fibre going to the bud or to an adjacent tree ending. There is also that form which occurs at the interlacing of fibres. In addition to these there are a number of swellings of many forms and sizes—oval, triangular, &c. Many of them are artefacts, but whether they can all be classed as such may be open to doubt. This, however, may be said: they are fewer in well-stained preparations and are larger and more numerous in nerves undergoing degeneration.

From the time Verson (1872) described the taste-buds of the larynx various opinions have been held in regard to their function. Verson held that the very fact that they are found in the posterior surface of the epiglottis is proof enough that they are not taste-buds. Krause believed that they were the organs "für intensive Nachgeschmacke."

That taste can be perceived in the upper part of the larynx cannot be doubted. My own investigations corroborate the statements of Michelson (1891) and Kiesow (1901-2) on this point. By means of the laryngoscopic mirror one can touch any desired point of the vestibulum laryngis. Taste perception is rapid and sufficiently accurate to differentiate more or less definitely the four primary tastes, though quantitatively and qualitatively inferior to the tongue.

The following hypotheses have been advanced to explain the presence of taste-buds in the larynx:—

(1) They are a phylogenetic residue.

(2) They are organs of taste whose chief function is to strengthen the reflexes which close the laryngeal cavity during the passage of food: "Die Reflexe zu verstärken wenn Geschmackstoffe in den Larynx gelangen" (Kiesow, 1901).

The first hypothesis is supported by: (*a*) The history of the taste-buds in the vertebrates—a history which shows a formerly widely diffused sense-organ becoming more restricted in locality; (*b*) the history of the taste-buds in the individual life of man, since in early life they cover a much wider area; (*c*) the statement that they can serve no function, as they never come into actual contact with food.

It must be acknowledged that the taste-buds have undergone a phylogenetic decrease, and that in the individual life of man their area of distribution diminishes. We have a corresponding phylogenetic decrease and restriction of area in the allied sense-organs of smell (Mann, 1905).

But restriction of area need not indicate a phylogenetic residue, and may equally well indicate a more specialised sense arising from a concentration of the area of peripheral sense. It is hard to believe that these organs have no function; their number, their abundant nerve supply, their persistence during life, their physiological activity, speak against the acceptance of this hypothesis. One feels that the reason for their continued presence here has to be sought in the intricate mechanism of deglutition.

In discussing the second hypothesis it is well to recall how great a part of the function of the larynx lies in protecting the entrance to the trachea (Anderson Stuart, 1892), and to note that the hypothesis which accounts for the closure of the larynx during deglutition as due to the mechanical lid-like action of the epiglottis cannot be upheld, and that the evidence clearly shows that closure of the aditus laryngis occurs by an approximation of the arytenoids,

by contraction of the soft parts together with their apposition to the inferior surface of the epiglottis (Anderson Stuart, 1892; Eykman, 1904). The primary purpose of taste was probably to select a suitable food supply, and so to act as a protective agent for the animal. What more suitable end-organ to assist in protecting the trachea during the passage of food could there be than one whose natural stimulus is the food? In the vestibule of the larynx those functionally active buds, particularly rich in their nerve supply, rest on an exposed surface in marked contrast to the concealed nature of these organs in the tongue; there is, therefore, a rapidity and facility of reaction of laryngeal buds in contrast to the persistence of functional activity apparent in those of the tongue. To this hypothesis the localisation of these organs lends additional support. They are not, as a rule, found at the apex; they become apparent near the middle and are most marked, very obviously so in the dog, on both sides of the line joining the aryteno-epiglottic fold. In man, so far as our preliminary investigations have shown, there are none at the apex of the epiglottis, but they lie round and beneath the cushion of the epiglottis. They are numerous on the medial surface of the arytenoid cartilage and on the lateral surface close to the apex. (Kalius, 1905.)

Further investigation will have to be made, especially as to whether or not a difference in intensity of closure of the larynx results from the application of sapid or non-sapid bodies; but even from the above one may well be justified in claiming some support for the hypothesis that these end-organs act as sentinels to assist in the protection of the laryngeal cavity during the passage of food.

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Explanation of Plates II. and III.

Plate II. A.

Section of the epiglottis of a rabbit. Taste-bud lying in a shallow depression of the epithelium with pore (*p*) communicating with the faintly outlined cavity (*bc*) in the upper segment of the bud. (*pg*) Nerve dividing in submucous tissue and finally breaking up into numerous branches, which form a network around the bud (perigemmal plexus); branches (*r*) are seen passing into the surrounding epithelium. (*sg*) Nerve-fibre branching frequently to form a network (only partly shown) at the base of the bud; it sends branches (*ig*) within the bud (intragemmal fibres). (*epn*) Nerve with epithelial endings.

Zeiss D. Comp. occ. 4.

Plate II. B and C.

Section from mucous membrane of vestibulum laryngis of dog, near base of epiglottis. (B) Bud with spindle-shaped cells (*s*) stained by methylene blue, showing relation of the intragemmal fibres to the cells. (*v*) Fine varicose fibre passing into bud. (C) Bud cut obliquely with the part adjacent to the pore not seen. The perigemmal plexus is connected with the nerve (*pg*). At the base a few bud cells are seen in outline.

Zeiss $\frac{1}{12}$ *oil immersion. Comp. occ.* 4.

Plate III. A.

Mucous membrane from larynx of dog near arytenoid cartilage. (*n*) Nerve-fibre which divides at (*r*) into two branches, of which one (*e*) goes to end in a subepithelial end-tree (Endbäumchen), the other (*pgn*) goes to form a plexus around the bud. The nerve (*sg*) winds spirally and branches at base; it finally sends off shoots (not shown) into bud. (*v*) Fine varicose nerve-fibre passing into the bud.

Zeiss D. Comp. occ. 4.

Plate III. B.

From epiglottis of a dog; lower segment of bud which has been cut obliquely. The nerve (*sg*) coils and branches in subgemmal connective tissue to form a plexus around the base of the bud (subgemmal plexus). From this plexus branches (*ig*) pass into the bud (intragemmal).

Zeiss $\frac{1}{12}$. *Comp. occ.* 4.

I am indebted to Mr. L. H. Wilder for the carefulness and accuracy with which he has prepared these drawings.

Review.

Mental Defectives. By MARTIN W. BARR, M.D. London, Rebman Limited, 1904, pp. 368.

Dr. Barr, who is chief physician to the Training School for Feeble-minded Children at the well-known institution at Elwyn, Pennsylvania, is well qualified by his position for writing a book on this important subject. He commences by giving the synonyms of idiocy, imbecility, &c., in different languages, and alludes to the definitions which have been applied by many authorities to this class of cases. In America, the term feeble-minded has been used to cover every form of mental defect, and it is well that this should be known, because in England this term "feeble-minded" has been used especially for cases above that of idiocy and imbecility, and it is children belonging to this feeble-minded class who go to the special classes and schools which have been established for them in London and different parts of the country. In fact, the Elementary Education (Defective and Epileptic Children) Act, 1899, expressly excludes imbeciles from these classes, as the imbeciles have insitutions built for them and an Act, the Idiots Act, 1886, under which these institutions work. Fifty-four pages are devoted to the history of the way in which different countries have taken up the work, and the education of the savage boy of the Aveyron by Ibard is fully described. The classifications of Esquirol, Duncan and Millard, Langdon-Down, Ireland, Shuttleworth, and Kerlin, who preceded him, are alluded to, and the author adds another one which has a chiefly educational foundation as distinguished from a pathological one. In the chapter on etiology the 2,380 cases collected by Fletcher Beach and Shuttleworth are mentioned, and the author compares with these 3,050 cases which he has collected from different sources. There are some differences, however: thus phthisis accounts for 28·31 cases in the English tables, but for only 7·57 in the American. Again, insanity and imbecility produce 21·38 in the English tables, but only 7·08 in the American. Epilepsy and other neuroses account for 20·00 in England, but only 5·58 in America. Intemperance, which produced 16·38 in England, only produced

4·46 in America, which seemingly would go to prove that the American race is more temperate than the English. However, causes acting before birth account for 64·85 cases, those at birth for 2·92, and those acting after birth to 32·23, and allowing for differences in numbers much the same ratio prevails in the English tables. The chapters on diagnosis, and training and treatment are excellent. In America, public opinion apparently is not so markedly against asexualisation as in England. The prevailing opinion in enlightened circles here is that hopeless cases should be shut up for life, but in America they would not only do that, but asexualise them as well. Dr. Pilcher, it appears, castrated fifty-eight boys, and in almost every case there was marked improvement, both mental and physical. The author's preference would be for oöphorectomy in the female and testiectomy in the male. Sixty-five pages are devoted to illustrative cases, and thirteen to the responsibility or irresponsibility of Samuel Henderson, a murderer. There is a copious bibliography at the end of the book, and there are a large number of photographs of cases, but in another edition these should be better arranged. For instance, when one is reading about epilepsy one does not wish to see photographs of cases of cretinism and myxœdema, and when reading the psychology of "idiots savants," photographs of microcephalus do not help one much. After all these are minor defects, and if anxious parents and earnest teachers for whom the author says the book is written will read, mark, and inwardly digest it, nothing but good can result.

FLETCHER BEACH.

PROCEEDINGS OF THE NEUROLOGICAL SOCIETY OF THE UNITED KINGDOM.

AT the Meeting held at the National Hospital, Queen Square, on Saturday, June 24, at 10 a.m., the following cases were shown:—

Dr. BEEVOR.—(*a*) *Progressive muscular atrophy, immobile pupils, exostosis on humerus.*

[12] A. R., male, aged 38, French polisher. Onset four years ago with cramps in fingers, wasting of thenar eminence and first interosseal space, forearm, and, lastly, biceps. No pain, numbness, nor loss of feeling. Disease seems to have progressed more rapidly in past six months. Gonorrhœa ten years ago. No history of lues. Married; no children; no miscarriages.

Present Condition.—Fairly well nourished. Bony exostosis under tendon of left biceps. Smaller one on right humerus. Pupils—pin-point, R. > L. Argyll-Robertson—Do not dilate to shade, dilate slightly to cocaine, vision $\frac{6}{6}$ R. and L. Symmetrical atrophy slight in triceps; marked in biceps, extensors, thenar eminence, abductor indicis and interossei. Weakness of corresponding movements.

Electrical reaction—Partial R. D. in atrophied muscles. Small muscles of thumb do not react to faradism or galvanism.

Reflexes.—Triceps, knee-jerks and ankle-jerks normal. Biceps and supinator-jerks absent. Plantars flexor.

(*b*) *Peroneal type muscular atrophy—familial type.*

[13] J. T. S., male, aged 38, tailor. Twenty-one years ago, difficulty in walking. Wasting of calf muscles followed by wasting of thenar eminence. Wasting has progressed more rapidly in last two years. No pain, tingling, nor loss of sensation. One brother and one sister similarly affected; both younger than patient. Brother is well advanced. Sister affected only in one foot. In neither are the hands affected.

Present condition.—Some wasting of forearms. Atrophy of small thumb muscles. Dorsal and palmar interossei. Weakness in corresponding movements. Some fibrillary twitchings in small muscles of thumb. Atrophy of calf muscles and peroneal group, pes equino varus. Weakness in corresponding movements of feet. Electrical examination shows change in or absence of reaction of muscles to faradism and galvanism.

Reflexes.—Triceps, biceps, supinator, and knee-jerks normal. Ankle-jerk absent. Plantar flexion, epigastric, abdominal, and cremasteric, normal.

Gait.—Can scarcely stand without mechanical support. Has had several operations of tendo-Achillis and plantar fascia performed by Mr. Fisher.

(*c*) *Mesencephalic lesion.*

[14] M. J., female, married, age 39. Eleven years ago staggered in walking. Seven years ago difficulty in speech and could not close right eye nor move either eye out. Five years ago stiffness in right arm, with ataxia. Two years ago regurgitation on swallowing. One year ago micturition difficult, numbness of fingers, diplopia. Eight months ago vision diminished.

On admission.—Slow, deliberate, staccato, syllabic speech, somewhat slurring, accompanied by side to side tremor of head; laughter explosive; visual field restricted to 5°. Post-neuritic atrophy.

Lateral conjugate deviation impossible; on attempt convergence of both. Upward and downward movement present; pupils equal and regular, react to light and accommodation. Paralysis of right side of face. Watch heard only when applied to ear.

Pharyngeal reflex absent, deglutition difficult, speech as above. Soft palate moves weakly, tongue protruded normally, inco-ordination and intention tremor.

Lower extremities rigid and inco-ordinate. Complete anæsthesia, analgesia; loss of sense of position, astereognosis; diminution in weight sense.

Reflexes:—Knee-jerks active, plantars right flexion, left (?) flexion; abdominal and epigastric slight.

Dr. J. H. Bryant.—(*a*) *Two cases of the peroneal type of family amyotrophy.*

[15] *Case* 1.—Lilian S., aged 12, first came under observation in April, 1901, for wasting of the muscles of the legs and hands.

Forceps were used at her birth, but there was no apparent injury to her brain. She began to walk at the age of 10 months. When 4 she had an attack of whooping cough, after which she was unable to walk properly. On account of this trouble she was taken to an Orthopædic Hospital, where a diagnosis of infantile paralysis was made, and she was ordered to wear boots with iron supports.

At this time both feet and legs were wasted up to the knees. When 5½ she had an attack of scarlet fever and at 6 and 8 attacks of measles. In January, 1900, wasting of the muscles of the hands was noticed.

Both her parents are strong and healthy. A paternal uncle is suffering from a similar disease characterised by weakness and wasting of the legs and hands. A brother (Case 2) is also affected with a similar disease. She has two brothers aged 18 and 17, who are quite well.

Condition.—The feet, hands and legs are weak. The gait is somewhat "high-stepping" in character. There is slight talipes varus.

There does not appear to be any loss of sensation to touch, pain, heat or cold, but it is curious that strong electrical stimuli applied to the hands cause no feeling of discomfort or pain.

There is marked wasting of the thenar, hypothenar and interossei muscles of both hands.

The muscles of the legs are much wasted.

There is no wasting of the deltoids, scapular or facial muscles. Slight fibrillation has been noticed at times in some of the muscles. There are no hypertrophied muscles.

The knee-jerks cannot be obtained. The plantar reflex is present, and is flexor in character. Neither wrist- nor elbow-jerks can be elicited.

On stimulation, both with the faradic and the galvanic currents there is no response in the thenar, hypothenar, and interosse muscles, the small muscles of the feet, the peronei, tibialis anticus and extensor longus hallucis.

[16] (*b*) *Case* 2.—Percy S., aged 8, first came under observation in August, 1903. Forceps were also used at his birth, but there was no apparent injury to the brain. He was able to walk and run about as other children until two and a half years ago, when he had an attack of measles, after which his mother noticed he was weak on his legs and could not lift his big toes. He seemed to be helpless, and began to fall down frequently on account of his legs giving way under him. When first seen,

the paralysis of the extensor longus hallucis muscles was the most striking feature.

He has become much worse, and now cannot walk at all by himself unless his legs are supported by straight internal splints extending from the foot to just below the knee.

The feet are dropped, the big toes are flexed, and the feet are in a condition of talipes equino varus and pes cavus.

The thenar and hypothenar muscles have commenced to waste.

An attempt was made to test the electrical reactions, but he was so frightened, and struggled so violently, that it was impossible to obtain any reliable data.

Dr. GEORGE OGILVIE.—*A case of tabetic gait beginning at the age of* 64.

[17] Male, aged 73, formerly a storekeeper. He was in good health up to the age of 64; since then progressive weakness and unsteadiness of the legs. Unable to walk alone during the last five years.

Present state.—Mental condition good. Speech slow and hesitating.

Lower limbs.—Strength poor, but no wasting. Cannot walk or stand alone. Tabetic gait. Knee-jerks absent. Much sweating of the legs and feet. Skin poorly nourished. No lightning pains or cramps. No anæsthesia. Muscular sense good.

Upper limbs.—Strength poor. Grip = $\frac{1}{4}$ normal. Slight tremor and inco-ordination.

Sight.—Becoming worse during last year. R. $\frac{6}{12}$, L. $\frac{6}{18}$. Pupils react to light and accommodation. Nystagmoid movements on extreme excursion. Slight general contraction of the fields of vision. Lenticular opacities. Subsiding optic neuritis, passing into atrophy on the left side.

No girdle sensation. No visceral crises. No incontinence.

Dr. H. CAMPBELL THOMSON.—*Case of tremor.*

[18] M. S., female, aged 34.

Fifteen months ago suffered considerable shock owing to the death of a relative, and soon after she noticed the left arm began to tremble.

There is now a rhythmical tremor of left arm, varying in intensity, but said to be never absent, except during sleep. It is usually rather worse during voluntary movement. General health is good.

Dr. T. D. Savill.—*A case of ataxy in a woman, aged* 40, *of twenty years' duration.*

[19] Margaret C., aged 40, has been unable to walk properly for twenty years. The difficulty came on quite suddenly sixteen days after a severe fright, consisting of her mistaken apprehension by the police. According to her own account, the difficulty of movement was almost as great then as it is now, and it has not varied much, excepting when she had "Viters's dance" thirteen years ago. There is no definite history of syphilis.

At the present time the symptoms are mainly two in number, *inco-ordination* of all the limbs, sufficient in the legs to prevent her walking or standing without crutches, unaccompanied by paralysis or atrophy, and increase of all the *tendon reflexes*, Babinski's reflex also being present. The speech has an explosive or staccato quality, suggestive of disseminated sclerosis, and the teeth are the seat of pyorrhœa alveoloris. The pupils, fundi, and fields of vision (tested by Mr. J. L. Tomlinson) are normal, and there is no nystagmus, no sensory or sensorial changes. Strong faradisation for two or three weeks has had no notable effect; suggestions as to treatment are solicited.

Dr. Lees and Mr. Ballance.—*Posterior-basic meningitis in a boy of* 3 *years, resulting in hydrocephalus, emaciation, and a comatose condition which had lasted for three weeks, during which he had not recognised his mother, and had required nasal feeding. Trephining: drainage of lateral ventricle by rubber tube into subarachnoid space for twenty-two days; cerebral hernia subsequently protected by insertion of a platinum plate. Complete recovery except for deaf-mutism.*

[20] The operation was performed by Mr. Ballance seven years ago (1898). The boy has remained in good health, and is being educated in a special school for deaf mutes. He is now 10 years old.

This is the successful case mentioned in the concluding words of the paper on "Simple Meningitis in Children," by Dr. Lees and Sir T. Barlow, in the seventh volume of Allbutt's "System." The case has not previously been exhibited at any Medical Society.

Dr. Thomas Buzzard.—(*a*) *Case of mesencephalic lesion.*

[21] E. P., aged 35, spinster. Suffered from fatigue seven years ago. Same time loss of vision. Tremor four years. Five years diplopia. Dimness of vision increased during past year. No history of headache or vomiting. No sphincter trouble.

Present condition—Discs pale and atrophic. Pigmentation of choroid. Complete ophthalmoplegia interna and externa. Pupils react to light, but not on accommodation. Teeth show well-marked trophic changes. Slight weakness of left face.

Gait.—Tends to deviate to right. Well-marked tremor on movement confined to right side. Reflexes, sensory system and muscular system normal.

(*b*) *Case of muscular wasting with unusual symptoms.*

[22] H. C., aged 45. June, 1904, aching pain right leg. September, 1904, right foot began to drop. Later weakness of right knee. January, 1905, burning pain in left foot. March, 1905, weakness of left leg. Thighs have wasted since November, 1904. Same time fibrillation of thighs and buttocks noted.

Present condition.—Congenital nystagmus. Marked fibrillation of upper extremity.

Lower extremity.—All movements of toes and ankles absent. Very slight flexion and extension of knee. Slight extension of thigh. All other movements absent. Muscles below knee do not react to faradism. React briskly to galvanism. No polar change. Ankle-jerks and plantar responses absent. All other reflexes present and normal. Sensory system normal.

Dr. F. E. Batten.—(*a*) *Congenital affection of sixth, seventh and twelfth cranial nuclei.*

[23] E. S., aged 9. First seen when 2½ years old, the condition having remained unaltered since that time.

The child has had facial paralysis since birth, and was never able to suck.

First child. Father and mother healthy.

Present condition.—Intelligent child, with partial paralysis of both sides of the face, the right being more affected than the left.

Complete paralysis of lateral movements of the eyes.

Convergence good. Pupils equal. React well.

Atrophy of the tongue, both sides.

Knee-jerks active. Plantars flexor.

(*b*) *Case of tremor of right arm associated with epilepsy.*

[24] R. C., girl, aged 20. Twitching of right hand first noticed in April, 1904, and shortly after this patient had a fit in which she fell, but did not bite her tongue. No headache or vomiting.

The girl has quick, sudden contractions of the muscles of the right arm, which became more marked on intention movement. The power of the hand is good.

There is no sign of organic disease. The plantar reflexes are difficult to obtain. Epileptic fits occur at irregular periods—but are controlled by bromides. No improvement has taken place in the condition during the past twelve months.

(*c*) *Case of acute ataxia in a boy.*

[25] The boy, aged 3½, had measles in March, 1904, and there was a family history of tuberculosis. Upon being got up he became dazed and then unconscious, and remained so for a week. He then had convulsions and tremors, and on regaining consciousness he could not sit up nor speak. A month later he had marked inco-ordination of both legs and arms. There was no paralysis. The knee-jerks were well marked, with a tendency to ankle clonus. Plantars generally flexor. He swallowed well, and spoke in a low, hesitating manner. He has complained of pins and needles in his limbs. His mother complains that since his illness his moral sense has become much perverted. He was seen again in May, 1905, and marked improvement had taken place in his gait.

Knee-jerks still active. Plantars flexor.

Dr. A. F. Voelcker.—(*a*) *Case of acute ataxy.*

[26] D. F., aged 4¾ years, female.

This child was shown at a meeting of the Neurological Society on March 30, 1905, as an example of acute ataxy.

She was supposed to have had an attack of scarlet fever in Christmas, 1904, in which she became unconscious for fourteen days; gradually regained consciousness, but has been unable to stand or feed herself since. Her speech was lost, but has gradually been returning. No vomiting during the initial illness.

On admission the child was unable to walk or even stand, and could hardly sit up alone in bed. Marked tremor of the head. When supported, her gait is very markedly ataxic; the toes are pointed down. At times progression is cross-legged. Some ataxy of upper limbs. Some tendency to fall backwards.

Marked muscular hypotonus. Plantar reflexes variable, frequently extensor on the left side. Knee-jerks brisk; no A.C. Speech slow, drawling, indistinct.

During May the child has improved somewhat, and makes very little effort to walk.

The knee-jerks are less readily obtained. The ataxy of both lower and upper limbs is less, and the mental condition is improving.

(*b*) *Case of* (*?*) *disseminated sclerosis.*

[27] M. C., aged 11, female. In June, 1903, she was noticed to be losing her power of walking, and to become weak in the arms and legs, and to have difficulty with her speech. This has been getting gradually worse.

Since January, 1905, she has been unable to walk or stand, and has been unable to feed herself. The impairment of speech has not become more marked. There has been no vomiting, and only an occasional headache. She has, however, complained occasionally of pain in the lower part of the back and in the back of the neck. She has occasional attacks of vacancy.

Well nourished, skin pigmented. Upper central incisor notched. Spleen felt 1½ ins. below the costal margin. No scars or other evidence of congenital syphilis.

Nervous system.—Fairly intelligent. At times emotional, at others apathetic.

Speech.—Slow, drawling.

Motor.—Can move all her limbs. Grip good. No muscular wasting. Marked intention tremor, especially in upper limbs.

Gait.—Very unsteady. Can only stand and walk with support. Gait ataxic, but feet plantar in fairly regular series of positions. No cross-legged progression. Marked tremor of head when patient drinks. Voluntary movements increase the tremor of the upper limb. No tremors during repose.

Sensory.—Beyond a slightly prolonged latent period nothing abnormal detected.

Cranial nerves.—No optic neuritis or atrophy. No nystagmus. Pupils react to light and accommodation. No palate palsy.

Reflexes.—Plantars variable, more often flexor than extensor, sometimes not obtained.

Knee-jerks distinctly increased. No patellar clonus. No true ankle clonus. Reflexes of upper limb slightly exaggerated. Jaw-jerk not exaggerated. Sphincters natural.

Dr. H. Lewis Jones.—(*a*) *A case of paralysis of the upper extremity after a dislocation of the shoulder-joint, in which the distribution of paralysis was unusual.*

[28] The deltoid was almost unaffected and preserved normal reactions, but the biceps, brachialis anticus and supinator longus

were completely paralysed and showed a reaction of degeneration which is still present. Moreover, the clavicular portion of the pectoralis major preserved normal reactions, but the lower (sternal) part showed R. D.

[29] (*b*) *A case of bilateral atrophy of the intrinsic muscles of the hands coming on in a young female patient.*

The wasting has persisted for many years. Weak normal reactions present in the affected muscles.

Dr. HENRY HEAD.—(*a*) *Case of myoclonus.*

[30] W. G., aged 28. Nine years ago began to have "cramp" in the feet and hands. This was soon followed by tremors of the limbs, which have increased in violence, especially recently. The mother's brother is said to be in a similar condition.

He has had no fits. Always has been dull and has never done any work. He can stand and walk with difficulty. The elbows are flexed, forearms pronated, wrists flexed, and fingers extended. The legs are extended and somewhat rigid, the feet are inverted and pes cavus is greater on the right than left side. Coarse bilateral clonic movements at the rate of about 140 a minute are present in both arms, and in a less degree in the lower extremities. These cease during sleep. Sensation is not affected. Both knee-jerks are present, and are equal on both sides. No nystagmus. Discs are normal. The tongue is tremulous. Sphincters are unaffected.

(*b*) *A case of Huntingdon's chorea.*

[31] H. S., aged 38. A little more than twelve months ago he noticed that his legs began to tremble. About seven months ago his speech became affected. He is married and has four healthy children. His brothers and sisters and their children are healthy. No similar condition has appeared in any of his relatives except in his mother's sister who is now 83 years of age. At the age of 40 she is said to have begun to be restless, as he is now, and to have remained so until the present time.

He is a well-developed man, with no disease in the heart or lungs; the urine is unaffected. He speaks like a man who has difficulty in controlling his tongue; each word is begun with some difficulty, and some words are slurred, especially when he is in the presence of strangers. The tongue is extremely

unsteady. Face, hands, and legs are in constant restless movement, which is said to cease during sleep. Chest-wall and diaphragm participate in these irregular movements. Tremor is absent. The knee-jerks are normal, and the toes go downwards when the sole of the foot is stimulated. The pupils act normally, and micturition is not affected.

Dr. G. Newton Pitt.—*Case of Thomsen's disease (?)*

Dr. C. O. Hawthorne.—*Case of hemianæsthesia and hemianalgesia, with partial hemiplegia, in a man aged* 34. *Attributed to a blow on the head in November*, 1904.

Dr. Leonard Guthrie.—*Acute ataxy (encephalitis cerebelli).*

[32] Patient is a girl, aged 7 years. In February, 1904, at the height of an attack of measles with temperature 103°-104°, she developed cerebral symptoms, vomiting, convulsions, unconsciousness, followed by squint, retraction of head and photophobia. After five days all the acute symptoms subsided, but the patient was aphasic, seemed hyperæsthetic, and rapidly wasted. The optic discs were normal. A month later she was still aphasic, could not sit up or move lower limbs, the knee-jerks were exaggerated, ankle clonus present, but no Babinski plantar reflex was obtained. There were marked inco-ordination of the upper limbs and some athetoid movements of fingers. There was general anæsthesia to pin-pricks, but she recognised hot and cold, and appeared to fear pinching. All limbs were slightly rigid. Sphincter control was lost for two months. Then general improvement occurred. By the end of May, 1904, she could stand with support, feed herself and talk.

Present condition.—Healthy looking, well-nourished child. Slow mentally, but not deficient. Disposition docile and gentle. Speech drawling and bleating in character. Special senses normal. Eyes and pupils normal. Slight ataxy and tremors of upper extremities. She can stand alone and steadily when eyes are closed, but cannot walk more than a few steps without guidance. If left alone she reels, turns half round and falls backwards or to one side or the other. Loss of equilibrium seems due to ataxy in placing the feet rather than to vertigo. Gait is ataxic. Knee-jerks brisk; ankle clonus present at times. Plantar response negative or flexor.

Condition seems due to acute encephalitis affecting chiefly cerebellum or its peduncles.

Dr. WILFRED HARRIS.—*Case of transverse sacral myelitis (first sacral).*

[33] D. K., a Polish Jew, tailor, was seven years ago attacked suddenly by pain across sacral region, and convulsion of both legs for two hours. Since then the legs have always been weak, and his gait much as at present. Incontinence and precipitancy of both sphincters. Sphincter ani reflex good.

P.S.—Weak gait, no foot-drop. Wasting of right gastrocnemius, and especially of the intrinsic foot muscles on both sides. There is well-marked R. D. in the short flexors of toes, and sluggishness of contraction in R. gastrocnemius to faradism.

Knee-jerks normal. Achilles-jerks both absent.

Well-marked anæsthesia on feet and back of calves and buttocks, perinæum, and penis and scrotum, corresponding to the first sacral and lower segments.

Dr. JAMES TAYLOR.—(*a*) *Two cases of achondroplasia.*

(*b*) *Case of tremor of anomalous type in a brass-worker. ? metallic.*

Dr. GOLLA.—(*a*) *Syringomyelia.* (*b*) *Cerebral lesion.*

The afternoon was devoted to a Pathological Demonstration.

Communications by—

Dr. ALEXANDER BRUCE.—"On the Distribution of the Cells in the Intermedio-Lateral Tract in the Dorso-Lumbar Region of the Spinal Cord."

Dr. MOTT.—"On the Brain and Nervous System in Trypanosome Infections, including Sleeping Sickness, and the part played by Diplo-streptococci."

Sir VICTOR HORSLEY and D. R. H. CLARKE.—"On the Relation between the Cortex and Nuclei of the Cerebellum respectively, and the rest of the Nervous System, with Special Reference to a Fresh Method of Investigation."

Specimens Exhibited by—

Dr. LEWIS JONES.—(i.) Twelve photographs of tracings of current waves of medical coils, to illustrate the variety of curves

of those currents. (ii.) Induction coils to illustrate the curves of current waves. (iii.) Mechanical interrupters for the production of interrupted currents for diagnostic purposes.

Dr. C. E. Beevor.—Injected brains showing the vascular supply of the anterior, middle, and posterior cerebral, and of the anterior choroid and posterior communicating arteries.

Dr. L. Humphrey.—The parathyroid glands in Graves' disease.

Dr. W. B. Ransom.—Syringomyelia with neuro-epithelioma of the spinal cord.

Dr. Stanley Barnes.—(i.) Healed tubercular meningitis; death from secondary hydrocephalus. (ii.) Sarcomatosis of spinal pia, secondary to cerebral tumour.

Dr. R. T. Williamson.—(i.) Degeneration in the intramedullary fibres of the spinal posterior nerve roots in tabes dorsalis, diabetes mellitus, and intracranial tumours. (ii.) Changes in the spinal cord associated with severe anæmia.

Dr. E. Farquhar Buzzard.—The morbid anatomy of myasthenia gravis.

Dr. Hale White and Dr. F. A. Bainbridge.—Specimens from case of caisson disease.

Various other specimens from the Museum of the National Hospital were shown.

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EDITOR.